EPA

United States
Environmental Protection
Agency

LT1ESWTR Disinfection Profiling and Benchmarking
Technical Guidance Manual

Acknowledgements

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ABBREVIATIONS

List of common abbreviations and acronyms used in this document:

AWWA	American Water Works Association
BF	Baffling Factor
C	Residual Disinfectant Concentration
CFR	Code of Federal Regulations
CT	The Residual Disinfectant Concentration (mg/l) Multiplied by the Contact Time (minutes)
CWS	Community Water System
DBP	Disinfection Byproduct
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
EPA	Environmental Protection Agency
FBRR	Filter Backwash Recycling Rule
GAC	Granular Activated Carbon
gal	Gallons
gpm	Gallons per Minute
GWUDI	Ground Water Under Direct Influence of Surface Water
HAA5	Haloacetic Acids
hrs	Hours
IESWTR	Interim Enhanced Surface Water Treatment Rule
LT1ESWTR	Long Term 1 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MG	Million Gallons
mg/L	Milligrams per Liter
MGD	Million Gallons per Day
m/h	Meters per Hour
MRDL	Maximum Residual Disinfectant Level
NCWS	Non-community Water System
NTNCWS	Non-transient Non-community Water System

PWS	Public Water System
PWSID	Public Water System Identification
Q	Peak Hourly Flow Rate
RO	Reverse Osmosis
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
Stage 1 DBPR	Stage 1 Disinfectants and Disinfection Byproduct Rule
SWTR	Surface Water Treatment Rule
T	Contact Time (minutes)
TDT	Theoretical Detention Time
THM	Trihalomethanes
TOC	Total Organic Carbon
TT	Treatment Technique
TTHM	Total Trihalomethanes
UV	Ultraviolet
V	Volume
WTP	Water Treatment Plant
X log inactivation	Reduction to $1/10^x$ of original concentration by disinfection
X log removal	Reduction to $1/10^x$ of original concentration by physical removal
μ	Micron (10^{-6} meter)
μg/L	Micrograms per liter

MARGIN ICONS

Icons and text in the margins of this document highlight information and additional resources. These icons are shown below with brief descriptions of their uses or the types of information they may be used to highlight.

Indicates a reference to the federal regulations.

Indicates the need to consult with the State.

Indicates additional references or highlights important information.

Indicates worksheets.

Indicates sampling or data collection requirements.

Indicates applicability criteria.

Indicates a helpful hint or suggestion.
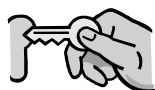
Highlights a key point or key information.

Indicates the next step.

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1. INTRODUCTION

40 CFR Section 141.501

1.1 PURPOSE OF DOCUMENT

This guidance manual is intended to help public water systems (PWSs) comply with the disinfection profiling and benchmarking requirements of the Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR). The requirements of the LT1ESWTR apply to PWSs that:

- Serve fewer than 10,000 people; and,

- Are classified as either surface water or ground water under the direct influence of surface water (GWUDI).

This manual explains disinfection profiling and benchmarking, discusses when and why they are necessary, and provides guidance as to how to compile a disinfection profile and how to calculate the benchmark. This guidance manual also discusses how systems and States may use these data to make decisions about disinfection practices. Copies of this document and other documents that pertain to LT1ESWTR may be obtained by:

- Contacting the appropriate State office;

- Calling the Safe Drinking Water Hotline at 1-800-426-4791;

- Downloading from EPA's website at http://www.epa.gov/safewater/mdbp/lt1eswtr.html; or,

- Calling the National Service Center for Environmental Publications at 1-800-490-9198 or visiting their website at http://www.epa.gov/ncepihom/.

Systems serving 10,000 people or more have different profiling requirements and should refer to the Interim Enhanced Surface Water Treatment Rule Guidance Document: Disinfection Profiling and Benchmarking, August 1999 (EPA 815-R-99-013).
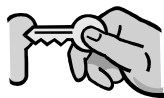
Key components of
LT1ESWTR.

1.2 OVERVIEW OF LONG TERM 1 ENHANCED SURFACE WATER TREATMENT RULE

The LT1ESWTR is a Federal regulation that establishes a treatment technique to control *Cryptosporidium*. The rule applies to public water systems serving fewer than 10,000 people and classified as either a surface water system or a GWUDI system. Key components of the LT1ESWTR are:

- Systems must provide a minimum of 2-log (99%) removal of *Cryptosporidium.*

- Systems with conventional or direct filtration plants must meet more stringent combined filter effluent turbidity limits and must meet new requirements for individual filter effluent turbidity.

- Systems using alternative filtration techniques (defined as filtration other than conventional, direct, slow sand, or diatomaceous earth) must demonstrate to the State the ability to consistently achieve 2-log (99%) removal of *Cryptosporidium* and comply with specific State-established combined filter effluent turbidity requirements.

- Systems that meet the filtration avoidance criteria must comply with additional watershed control requirements to address *Cryptosporidium.*

- Systems must develop a disinfection profile unless the State determines that the disinfection profile is unnecessary. The State can only make this determination if the system can demonstrate that the levels of Total Trihalomethanes (TTHM) and Haloacetic Acids (HAA5) are below 0.064 mg/L and 0.048 mg/L, respectively. The system must develop a benchmark if the system was required to develop a disinfection profile and subsequently plans a significant change to disinfection practices.

- New, finished water reservoirs must be covered.

- *Cryptosporidium* is now included in the Federal definition of GWUDI.

1.3 OVERVIEW OF DISINFECTION PROFILING AND BENCHMARKING REQUIREMENTS

40 CFR Sections 141.503 (c) and 141.503 (d).

The requirements for disinfection profiling and benchmarking described in this manual are part of the LT1ESWTR, published by EPA on January 14, 2002. The disinfection profiling and benchmarking requirements of the LT1ESWTR apply only to community and non-transient non-community water systems using surface water or GWUDI as a source and serving fewer than 10,000 people.

Transient water systems are not required to create a disinfection profile, unless directed by the State. However, transient systems are encouraged to use the profile as a tool to help evaluate their system.

40 CFR Section 141.530

A **disinfection profile** is a graphical representation of a system's level of *Giardia lamblia* (referred to as *Giardia*) or virus inactivation measured during the course of a year.

A **benchmark** is the lowest monthly average microbial inactivation during the disinfection profile time period. A disinfection benchmark is required only if a system was required to develop a disinfection profile and decides to make significant changes to its disinfection practices.

Systems should balance disinfection practices with Stage 1 Disinfectants and Disinfection Byproducts Rule requirements. See Section 1.4 for more information on this topic.

The LT1ESWTR requires systems to analyze their current disinfection practices before making changes to these practices. This analysis will result in a disinfection profile. Figure 1-1 depicts a sample disinfection profile.

Sample Disinfection
Profile

Figure 1-1. Sample Disinfection Profile

40 CFR Section 141.531

Each system must complete a disinfection profile *unless* the State determines that the system's profile is unnecessary. This determination will be based on TTHM and HAA5 levels in the distribution system. States may determine that a profile is unnecessary only if:

- TTHM <u>and</u> HAA5 samples are collected after January 1, 1998.

- The samples are collected in the month with warmest water temperature and at the point of maximum residence time in the distribution system.

- TTHM and HAA5 levels in the samples are less than 80% of the maximum contaminant level (MCL). This equates to TTHM <0.064 mg/L and HAA5 <0.048 mg/L.

Systems that do not have data meeting the avoidance criteria by July 1, 2003, for systems serving 500 to 9,999 people and January 1, 2004, for systems serving fewer than 500 people MUST begin to create a disinfection profile.

Systems that believe they have data that meet the avoidance criteria should consult with the State to determine whether they are required to profile. Systems not required to profile are encouraged to complete and use the profile as a tool to help evaluate their system.

40 CFR Section 141.532

40 CFR Section 141.536

CT = C x T
C = Residual disinfectant
concentration, mg/L
T = Contact time, minutes
See Chapter 4 for more
information on CT.

40 CFR Section 141.540

Systems serving 500 to 9,999 people must begin collecting data for the disinfection profile by July 1, 2003. Systems serving fewer than 500 people must begin collecting data for the disinfection profile by January 1, 2004.

In order to create a disinfection profile, systems should:

- Identify disinfection segments;

- Collect required data for each segment;

- Calculate CT; and,

- Calculate inactivation.

These topics are described in more detail in Chapters 2 - 5 of this document.

Systems must create and retain the profile in graphic form. The profile must be made available for review by the State as part of a sanitary survey.

Before any significant changes may be made to the disinfection process, a system must calculate the benchmark value based on disinfection practices. The benchmark is the lowest monthly average microbial inactivation during the disinfection profile time period (See Chapter 6 for more detail). The system is required to calculate a benchmark if both of the following apply:

- The system is required to complete a disinfection profile;

  and,

- The system plans to make a significant change to disinfection practices.

Systems must also consult with the State for approval <u>before</u> making any significant change to disinfection practices.

40 CFR Section 141.541

1.3.1 Significant Changes to Disinfection Practices

Significant changes to disinfection practice include:

- Changes to the point of disinfection;
- Changes to the disinfectant(s) used in the treatment plant;
- Changes to the disinfection process; or,
- Any other modification identified by the State.

1.3.2 Obtaining State Approval for Significant Changes to Disinfection Practices

40 CFR Section 141.542

If a system is required to complete a disinfection profile and intends to make a change as listed in Section 1.3.1, it must consult with the State for approval. The following information must be submitted to the State:

- A description of the proposed change;
- The disinfection profile for *Giardia lamblia (*and, if necessary, viruses) and disinfection benchmark;
- An analysis of how the proposed change will affect the current levels of disinfection; and,
- Any additional information requested by the State.

The flowchart in Figure 1-2 provides information on the LT1ESWTR disinfection profiling and benchmarking requirements.

Figure 1-2. Disinfection Profile and Benchmark Decision Tree
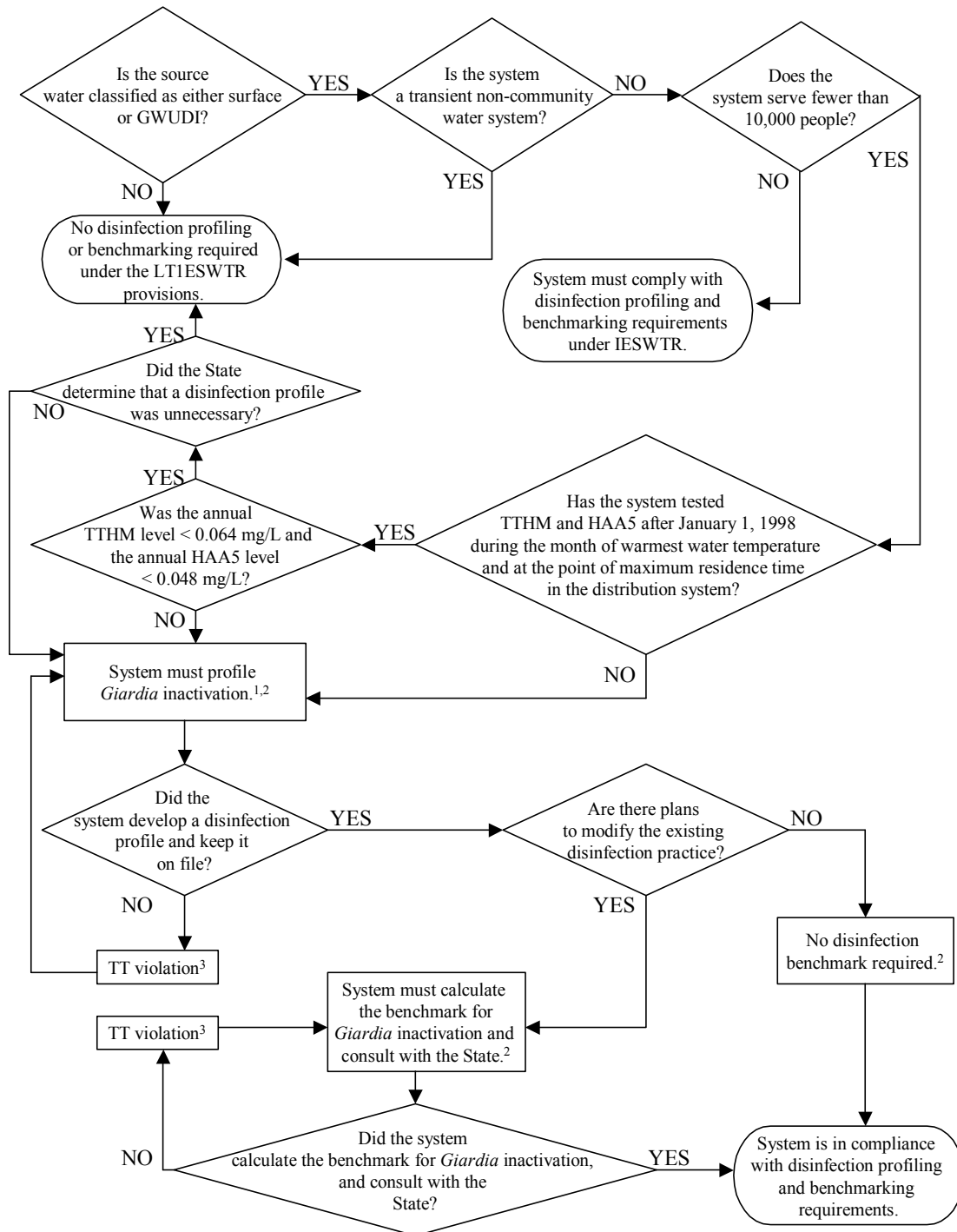
1. If using chlorine dioxide, ozone, or chloramines as a primary disinfectant the system must profile and benchmark viral inactivation as well.
2. Disinfection profile must be kept on file for State to review during sanitary survey.
3. Tier 2 violation. Public notification is required within 30 days.

1.4 USING DISINFECTION PROFILING AND BENCHMARKING TO BALANCE RULE REQUIREMENTS

Systems must balance disinfection practices with Stage 1 DBPR requirements. The disinfection profile and benchmark information will assist systems and States with achieving this balance.

More information on the Stage 1 DBPR is available at EPA's website (http://www.epa.gov/safewater/mdbp/implement.html).

Systems may be considering changes to disinfection practices during the disinfection profiling process to address Stage 1 DBPR requirements. Systems should contact the State prior to making changes to disinfection practices and discuss how these changes will affect the disinfection profiling process.

The LT1ESWTR disinfection profiling and benchmarking requirements will protect public health by assessing the risk of exposure to *Giardia* and viruses as systems begin to take steps to comply with Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) requirements. For systems classified as either surface water or GWUDI serving fewer than 10,000 people, the MCLs for TTHM and HAA5 become effective January 1, 2004. The Stage 1 DBPR established an MCL of 0.080 mg/L for TTHM and 0.060 mg/L for HAA5.

TTHM are the sum of the concentrations in milligrams per liter of the trihalomethane compounds (trichloromethane [chloroform], dibromochloromethane, bromodichloromethane, and tribromomethane [bromoform]). The MCL for TTHM is 0.080 mg/L starting January 1, 2004. Prior to January 1, 2004, there is no Federal MCL for TTHM for systems serving fewer than 10,000 people.

HAA5 are the sum of the concentrations in milligrams per liter of the haloacetic acid compounds (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid). The MCL for HAA5 is 0.060 mg/L starting January 1, 2004. Prior to January 1, 2004, there is no Federal MCL for HAA5 for systems serving fewer than 10,000 people.

In order to meet the requirements of the Stage 1 DBPR, systems may have to consider changes to their disinfection practices. Disinfection byproducts (DBPs) such as TTHM and HAA5 are formed when organic materials react with disinfectants such as chlorine. Therefore, systems with high levels of DBPs may need to modify disinfection practices to reduce the formation of DBPs. However, changes such as the use of lower concentrations of disinfectant will also lessen microbial inactivation. Decreasing the amount of disinfectant too much may produce water of unsatisfactory microbial quality. Disinfection profiling and benchmarking will help to ensure that no significant reduction in microbial protection results as a system changes disinfection practices to meet the TTHM and HAA5 MCLs under Stage 1 DBPR.

1.5 CONTENTS OF THIS GUIDANCE DOCUMENT

Contents of Document

This document is organized in the following sections and chapters:

- **Chapter 1 - Introduction**

- **Chapter 2 –Disinfection Segment**

  This chapter defines the term disinfection segment and describes how a system would identify the disinfection segment(s).

- **Chapter 3 – Data Collection**

  This chapter presents the data collection requirements for creating a disinfection profile.

- **Chapter 4 – Calculating CT**

  This chapter presents information and examples on how to calculate CT to be used in the development of a disinfection profile.

- **Chapter 5 –Calculating Inactivation**

  This chapter presents information and examples on how to calculate *Giardia* and virus inactivation values to be used in the development of a disinfection profile.

- **Chapter 6 – Developing the Disinfection Profile and Benchmark**

  This chapter provides information on how to develop a disinfection profile using calculated inactivation values. This chapter also presents information on when the disinfection benchmark must be calculated and how to calculate the benchmark.

- **Chapter 7 – Evaluating Disinfection Practice Modificiations**

  This chapter discusses how the disinfection profile and benchmark can be used to assess system modifications that may be considered for compliance. It also discusses the issues associated with each modification.

Contents of Document

- **Chapter 8 – Treatment Considerations**

  This chapter presents case studies and other information that may assist systems with LT1ESWTR and other rule compliance.

<u>Appendices</u>

- **Appendix A – Glossary**

- **Appendix B – CT Tables**

- **Appendix C – Blank Worksheets**

- **Appendix D – Examples**

- **Appendix E – Tracer Studies**

- **Appendix F – Calculating the Volume of each Sub-unit**

- **Appendix G – Baffling Factors**

- **Appendix H – Conservative Estimate and Interpolation Examples**

2. DISINFECTION SEGMENT

All monitoring points are located before or at the first customer (40 CFR 141.533(d)).

Systems need to identify disinfection segments. A disinfection profile must be developed using all disinfection segments.

2.1 INTRODUCTION

The first step in developing a disinfection profile should be to identify the disinfection segments within the plant. A **disinfection segment** is a section of a treatment system beginning at one disinfectant injection or monitoring point and ending at the next disinfectant injection or monitoring point. Every disinfectant injection point is the start of a new disinfection segment. Every injection point has an associated monitoring point. However, a plant may have only one disinfectant point, and choose to monitor at two or more points, creating two or more disinfection segments. A system must monitor the residual disinfectant before or at the first customer (40 CFR Section 141.533(d)). The disinfection segment could include distribution pipes and storage tanks located prior to the first customer.

Plants with multiple treatment trains will have multiple disinfection segments. If the treatment trains are identical, and flow is split equally, the disinfection segments for each train should be the same. If the treatment trains are very different, the system should identify all disinfection segments and develop a disinfection profile for each train separately.

2.2 IDENTIFYING DISINFECTION SEGMENTS

The suggested starting point for analyzing a plant is to develop a summary of the unit processes, disinfectant injection and monitoring points. It may be helpful to use a sketch or plan drawing of the plant. Drawings like those shown in Figures 2-1 through 2-6 may help in defining disinfection segments.

2.2.1 Single Disinfection Segment

Figure 2-1 shows a simple plant, with one injection point and one monitoring point, resulting in a single disinfection segment. The disinfection segment begins at the chlorine injection point prior to the clearwell and ends at the monitoring point after the clearwell.

Example:
Single Disinfection
Segment
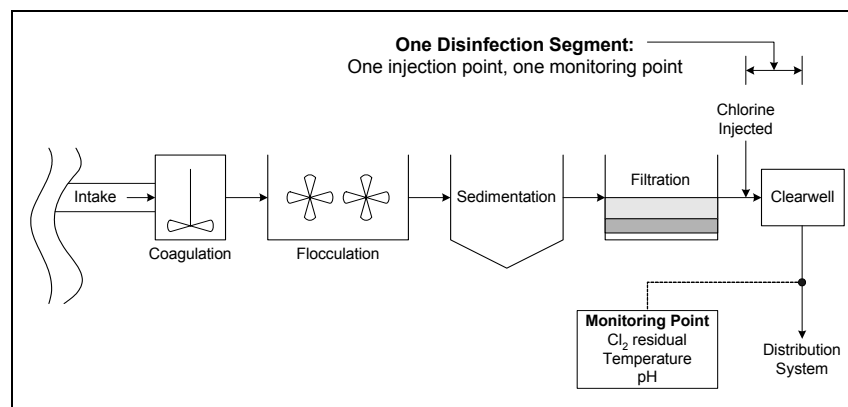
Figure 2-1: Plant Schematic Showing A Conventional Filtration Plant With One Disinfection Segment

2.2.2 Multiple Disinfection Segments

Figure 2-2 is an example of a system with two injection points and two monitoring points, resulting in two disinfection segments. Disinfection Segment 1 starts at the chlorine injection point (prior to the coagulation basin) and ends at the monitoring point after the filters. Disinfection Segment 2 starts at the chlorine injection point after the first monitoring point (between the filter and the clearwell) and ends at the monitoring point after the clearwell and prior to the first customer. Even for this simple plant, the analysis of how much disinfection takes place in the plant may be complicated. In this example, disinfection occurs in the coagulation basin, flocculation basin, sedimentation basin, filter, and clearwell, as well as in all the associated piping.

Example:
Two Disinfection Segments
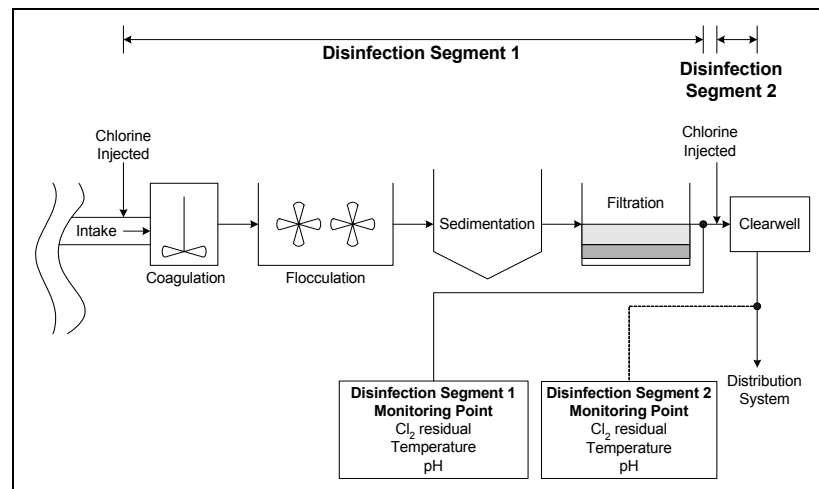
Figure 2-2: Plant Schematic Showing Two Disinfection Segments

Figure 2-3 is an example of a system with one injection point and multiple monitoring points. Although the system is required to have a minimum of one monitoring point, the chlorine is sampled in four locations to obtain higher chlorine residual values throughout the treatment train for Surface Water Treatment Rule (SWTR) compliance as opposed to monitoring at one location after the clearwell where the chlorine residual will be much less than measurements prior to the clearwell. The first disinfection segment starts at the chlorine injection point and ends at the first sampling point (between the coagulation and flocculation basins). The next three disinfection segments begin at one sampling point and end at the following sampling point. Therefore, even though there is only one injection point at this system, there are four disinfection segments.

Example:
Multiple Disinfection Segments

Chlorine residuals tend to decline as water moves through the treatment plant. The benefit of monitoring the chlorine residual at multiple locations is to obtain additional credit for the higher chlorine levels that exist at intermediate points in the plant. See Chapter 4 for more on the benefits of higher measured chlorine concentrations when calculating log inactivations.
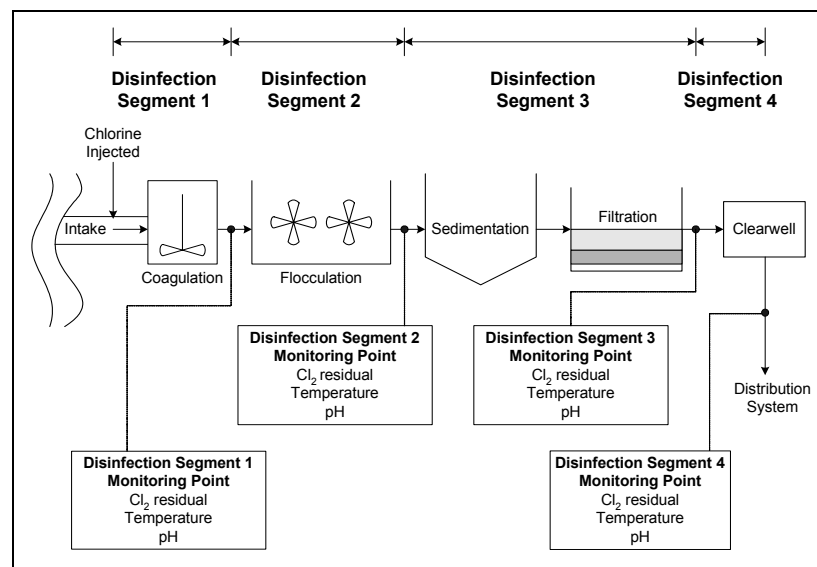
Figure 2-3: Plant Schematic Showing One Injection Point with Multiple Disinfection Segments

Figure 2-4 is an example of a more complicated plant schematic where the plant's multiple disinfection segments have been defined. In Figure 2-4 chlorine is sampled in three locations to obtain additional credit for higher chlorine residual values that exist at intermediate points in the plant. Ammonia is added prior to the clearwell to form chloramines. The use of a different disinfectant results in a new disinfection segment.

Example:
Multiple Disinfection Segments
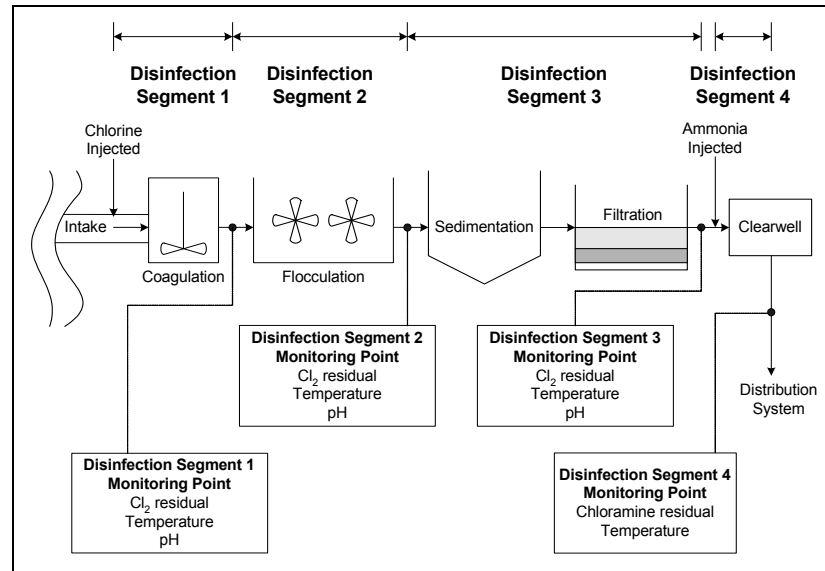
Figure 2-4: Plant Schematic Showing Two Injection Points with Multiple Disinfection Segments

2.2.3 Disinfection Segments for Multiple Treatment Trains

For some system configurations, one profile would not accurately characterize the entire treatment process. In these cases, multiple profiles are suggested. Figure 2-5 shows a plant with multiple treatment trains and multiple disinfection segments. In this example, the treatment trains are identical in that all unit processes in both trains have the same dimensions, operating rates, and hydraulic capacity. Since the treatment trains are identical, and flow is split equally between the treatment trains, the disinfection profile for Disinfection Segments 1a and 1b should be identical. Similarly, the disinfection profile for Disinfection Segments 2a and 2b should be identical. However, systems should check with the State to determine if separate disinfection profiles are required for each treatment train.

Example: Disinfection Segments for Identical Treatment Trains
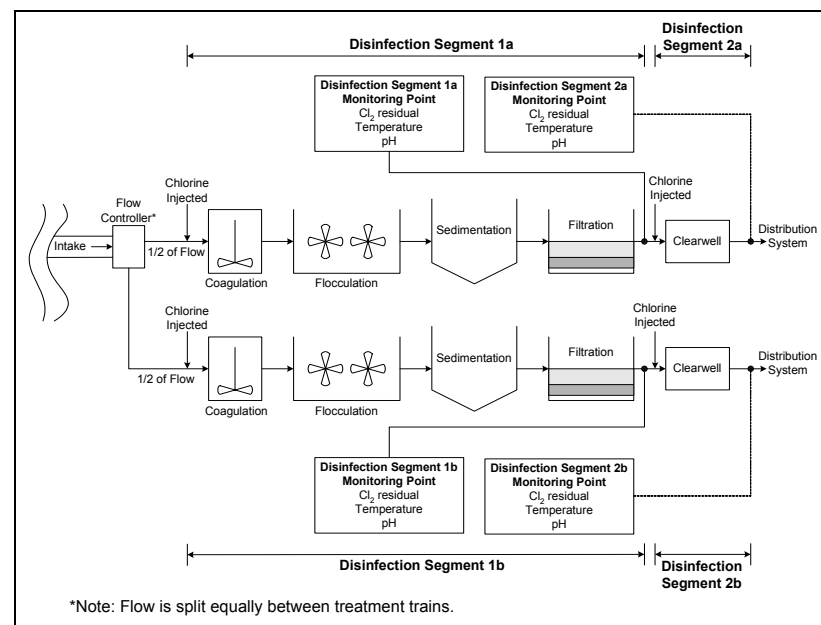
Figure 2-5: Plant Schematic Showing Identical Treatment Trains and Multiple Disinfection Segments

Figure 2-6 shows a plant with two treatment trains and multiple disinfection segments. Although the treatment trains are identical, in this example, the flow is not split equally between the treatment trains. The disinfection profile for Disinfection Segments 1a and 1b may not be identical. Similarly, the disinfection profile for Disinfection Segments 2a and 2b may not be identical. Therefore, this plant should develop a separate disinfection profile for each treatment train. Again, the system should check with the State on this issue.

Example: Disinfection Segments for Multiple Treatment Trains
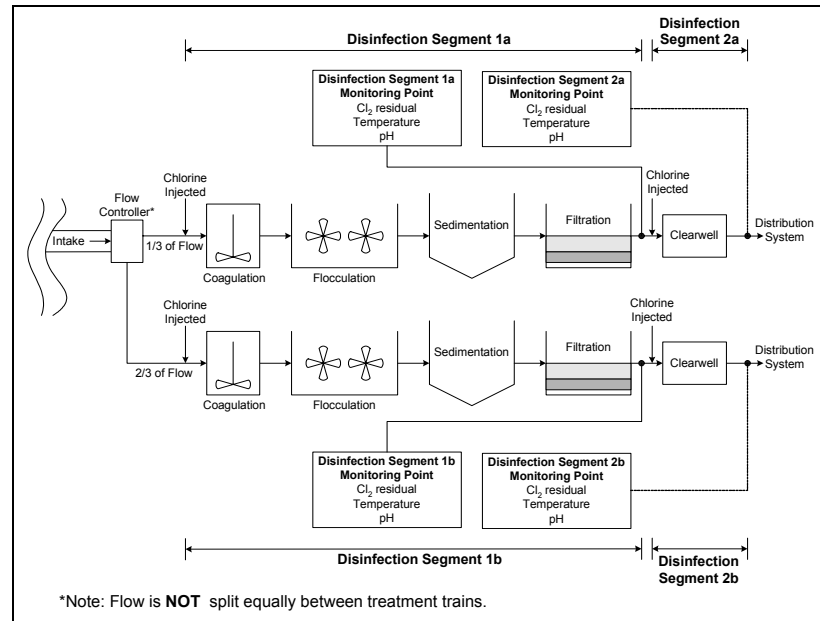
Figure 2-6: Plant Schematic Showing Multiple Treatment Trains and Multiple Disinfection Segments

2.3 STEPS COMPLETED
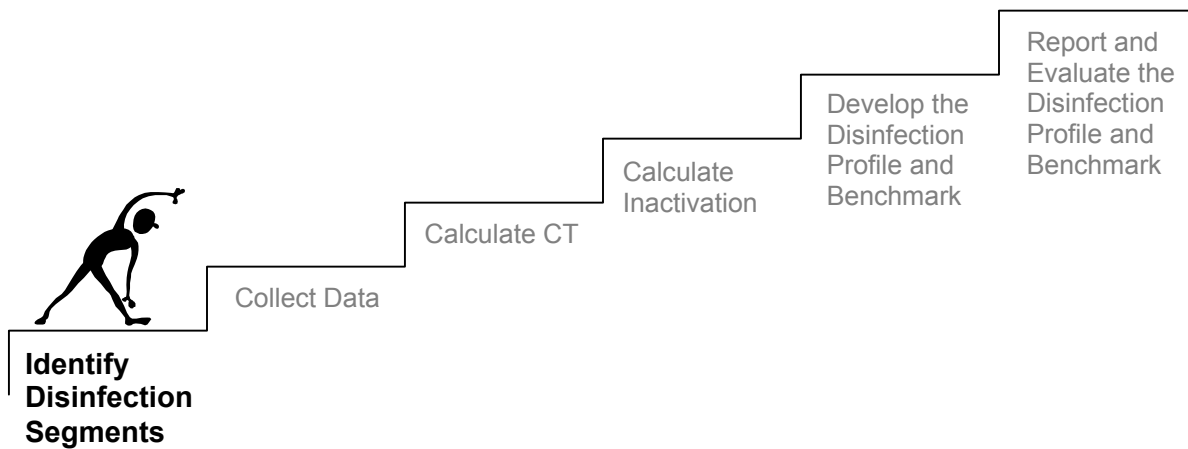
2.4 NEXT STEP

After all of the disinfection segments have been identified, data must be collected for each disinfection segment. See Chapter 3 for more information on disinfection profiling data collection requirements.

3. DATA COLLECTION

In this Chapter:
- Data Needed for the Disinfection Profile
- Data Collection Worksheets
- Steps Completed
- Next Step
- References

40 CFR Section 141.532

40 CFR Section 141.533

3.1 INTRODUCTION

Once a system has identified all disinfection segments, data must be collected for each segment to create the disinfection profile. For systems serving 500 to 9,999 people, data collection must begin no later than July 1, 2003. For systems serving fewer than 500 people, data collection must begin no later than January 1, 2004. Systems that are required to develop a disinfection profile must collect data once a week, on the same day of the week, for twelve consecutive months (one year). The State may allow the use of a more representative data set for disinfection profiling, so systems with sufficient historic data should check with the State prior to collecting data (40 CFR Section 141.530).

3.2 DATA NEEDED FOR THE DISINFECTION PROFILE

To develop a disinfection profile, data must be collected once per week on the same day of the week for one year. The following data are needed for each disinfection segment identified (See Chapter 2 for information on disinfection segments):

- **Peak Hourly Flow;**
- **Residual Disinfectant Concentration;**
- **Temperature;** and,
- **pH** (if chlorine is used).

Measurements must be taken on the same day of the week, every week, for one year (52 measurements), during peak hourly flow for that day. Data can be measured manually or with on-line instrumentation.

Systems that already have existing data that meet the criteria of Section 3.2 may wish to contact the State to determine if the existing data can be used to create a disinfection profile in lieu of collecting new data.

3.2.1 Peak Hourly Flow Rate

The amount of time the water is in contact with the disinfectant is a function of flow rate. When the flow rate increases, the time the water spends in the plant decreases. Using the peak hourly flow rate (required by LT1ESWTR) for analysis provides a conservative value for contact time. Some systems may be able to use a single peak hourly flow across the plant. In some systems, the peak hourly flow may vary across the plant. If the system has multiple disinfection segments and flow does vary across the plant, the disinfection segments may have different peak hourly flows.

All data must be collected at peak hourly flow.

Each system will determine its peak hourly flow rate differently. Some possible ways to determine the flow rate are:

- Flow meter records;

- Design flow rate;

- Maximum loading rates to the filters or other treatment process units;

- Raw water pump records; or,

- Historical maximum flow rate.

Data needed for each disinfection segment:
- Peak Hourly Flow
- Residual Disinfectant Concentration
- Temperature
- pH (if chlorine is used)
- Volumes and Baffling Factors (See Chapter 4)

When determining peak hourly flow, systems may want to take into consideration the location of their disinfection segment. For example, a system with a single disinfection segment with disinfection prior to the clearwell may consider using clearwell pumping rates versus raw water pump records to determine the peak hourly flow rate.

When compiling data for the disinfection profile, systems will monitor once per week on the same calendar day during peak hourly flow for residual disinfectant concentration, pH (if chlorine is used), and temperature.

Systems with supervisory control and data acquisition (SCADA) systems will be able to review records, identify the peak hourly flow, and then obtain the residual disinfectant concentration, temperature, and pH (if chlorine is used) that were recorded during peak hourly flow. Those systems without SCADA will need to coordinate with the State to develop a procedure that allows the system to best identify peak hourly flow to allow data collection. Some suggested approaches are:

- Determine when peak hourly flow occurred the day before data must be collected. Collect the residual disinfectant concentration, temperature, and pH (if chlorine is used) on the required day at the time peak hourly flow occurred on the previous day.

- Using the above approach, collect residual disinfectant concentration, temperature, and pH (if chlorine is used) at three different times (such as before, during, and after) near the time peak hourly flow occurred on the previous day. Then, based on pump records or other information, determine when peak hourly flow actually occurred and use the data that were collected nearest to the time of peak hourly flow.

3.2.2 Residual Disinfectant Concentration

The residual disinfectant concentration is monitored for each disinfection segment during peak hourly flow and is measured in milligrams per liter (mg/L). At least one monitoring point must be associated with each disinfectant injection point. However, systems may choose to sample for residual disinfectant concentration at more than one location for each unique injection point. The residual disinfectant concentration must be measured using methods listed in *Standard Methods for the Examination of Water and Wastewater*, 18th (1992), 19th (1995), or 20th (1998) editions. For those systems using ozone, Method 4500-03 B, contained in *Standard Methods for the Examination of Water and Wastewater*, 18th (1992) or 19th (1995) editions must be used. If approved by the State, residual disinfectant concentrations for free chlorine and combined chlorine may be measured using DPD colorimetric test kits.

$CT = C \times T$
C = Residual disinfectant concentration, mg/L
T = Contact time, minutes
See Chapter 4 for more information on CT.

CT is a measure of the strength of the disinfectant for the time that the water and disinfectant are in contact. CT is determined by multiplying the residual disinfectant concentration (C) by contact time (T). Monitoring the residual disinfectant at more than one location results in higher CT values since the residual disinfectant concentration decreases with each subsequent treatment process. For more information on CT refer to Chapters 4 and 5.

3.2.3 Temperature

The temperature is measured at each monitoring point and at the same time as the residual disinfectant concentration (during peak hourly flow). The temperature should be measured in degrees Celsius (^{o}C) because the CT Tables in Appendix B are based on temperature as measured in ^{o}C (See Chapter 5 for an explanation of CT tables). Temperature is important since the effectiveness of all disinfectants is temperature sensitive. Temperature must be measured using Method 2550 in *Standard Methods for the Examination of Water and Wastewater*, 18th (1992), 19th (1995), or 20th (1998) editions.

3.2.4 pH

If a system uses chlorine as a disinfectant, pH must be monitored because chlorine is pH-sensitive and is more effective at lower pH values. The pH is sampled at each sampling point and at the same time as the residual disinfectant concentration (during peak hourly flow). The CT tables in Appendix B for chlorine are based on pH. Systems must measure pH using EPA Method 150.1 or 150.2, ASTM method D1293-95, or Method 4500-H$^+$ in *Standard Methods for the Examination of Water and Wastewater*, 18th (1992), 19th (1995), or 20th (1998) editions.

If monitoring in ºF, use the following formula to convert from ºF to ºC:

$$^oC = \frac{5}{9} \times (^oF - 32)$$

Example 3-1: Collecting Data for a Disinfection Profile

Collect the data necessary for developing a disinfection profile for the system shown below.

Example: Collecting data for a single disinfection segment.

Example 3-1 continued

Step 1. Determine the peak hourly flow.

From the clearwell pump records the peak hourly flow is determined to be 347 gallons per minute (gpm).

Step 2. Measure the chlorine residual, temperature, and pH (since chlorine is used) during peak hourly flow at the same monitoring point and at the same time.

During peak hourly flow the following measurements are recorded at the same monitoring point at the same time:

Chlorine residual = 0.8 mg/L
pH = 6
Temperature = 0.5 $^{\circ}$C

Worksheet #1 in Appendix C can be used to record water quality data for the disinfection profile. The worksheet excerpt on this page demonstrates how to record the data from this example using Worksheet #1 in Appendix C.

Some systems may operate the plant at a low pH (for instance, a pH of 6) to achieve enhanced coagulation or more microbial inactivation (if chlorine is used). However, systems should consider increasing the pH prior to sending the finished water to the distribution system to avoid corrosion issues.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year: <u>2004</u>   PWSID: <u>AA1234567</u>   System/Water Source: <u>XYZ Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: <u>Joe Operator</u>
Profile Type (check one): <u>X</u> *Giardia*   <u> </u> Viruses

Disinfection Segment/Sequence of Application: <u>Clearwell/1st</u>

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. ($^{\circ}$C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT$_{Calc}$ = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.8	6	0.5	347								
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

Example 3-2: Collecting Data for Multiple Disinfection Segments

Example: Collecting data for multiple disinfection segments.

Collect the data necessary for developing a disinfection profile for the system shown below.
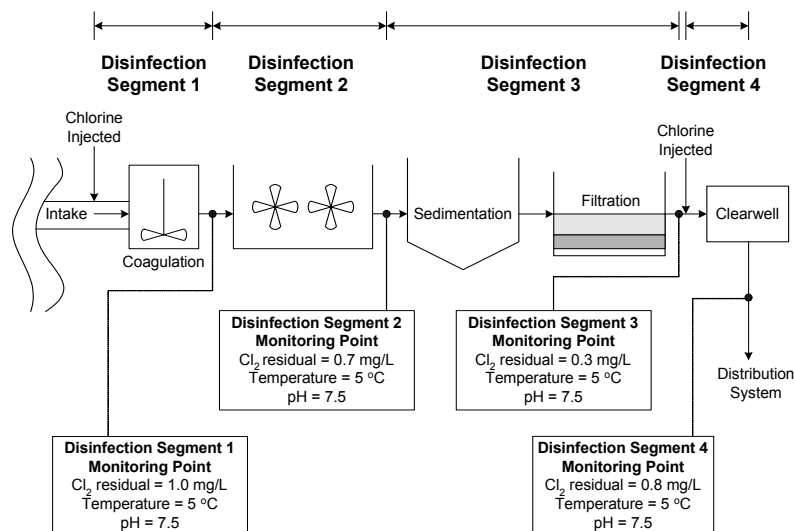
Step 1. Determine the peak hourly flow for Disinfection Segments 1 through 4.

From the raw water pump records the peak hourly flow is determined to be 347 gpm for Disinfection Segments 1, 2, and 3.

From the clearwell pump records the peak hourly flow is determined to be 370 gpm for Disinfection Segment 4.

Step 2. Measure the chlorine residual, temperature, and pH (since chlorine is used) during peak hourly flow at the same monitoring point and at the same time.

During peak hourly flow the following measurements are recorded at the same monitoring point at the same time:

Disinfection Segment	Chlorine Residual (mg/L)	Temperature (^oC)	pH
1	1.0	5	7.5
2	0.7	5	7.5
3	0.3	5	7.5
4	0.8	5	7.5

Example 3-2 continued

Again, Worksheet #1 in Appendix C can be used for data collection, as shown in Example 3-1. A new copy of Worksheet #1 should be used for each disinfection segment for systems with multiple segments. Example D-2 in Appendix D illustrates how to complete Worksheet #1 for multiple disinfection segments.

3.3   DATA COLLECTION WORKSHEETS

The worksheets in Appendix C are helpful for recording collected data. Systems should verify that their State will accept the worksheets for recordkeeping and reporting purposes.

3.4   STEPS COMPLETED

Report and
Evaluate the
Disinfection
Profile and
Benchmark

Develop the
Disinfection
Profile and
Benchmark

Calculate
Inactivation

Calculate CT

Collect Data

Identify
Disinfection
Segments
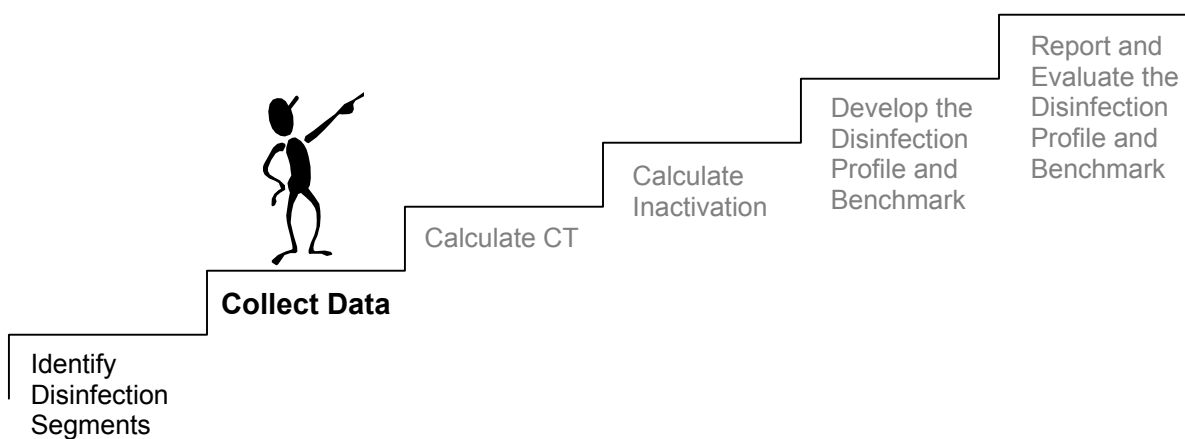
3.5   NEXT STEP

Now that data have been collected for each disinfection segment, the CT value can be calculated. Chapter 4 explains how to calculate CT.

3.6 REFERENCES

APHA, AWWA, WEF. 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. APHA, Washington, D.C.

APHA, AWWA, WEF. 1995. *Standard Methods for the Examination of Water and Wastewater*, 19th Edition. APHA, Washington, D.C.

APHA, AWWA, WEF. 1992. *Standard Methods for the Examination of Water and Wastewater*, 18th Edition. APHA, Washington, D.C.

4. CALCULATING CT

In this Chapter:
- CT
- Determining "C"
- Determining "T"
- CT_{calc}
- Steps Completed
- Next Step
- References

40 CFR Section 141.532

CT_{calc} - The CT that is calculated for a given disinfection segment.

Equation 4-1
$CT_{calc} = C \times T$

4.1 INTRODUCTION

If a system is required to complete a disinfection profile, it must calculate the CT value for each disinfection segment, known as CT_{calc}. System operational data and other data must be collected to determine CT_{calc} weekly for one year. Systems will collect data once a week, on the same day of the week, for twelve consecutive months (one year). For systems serving 500 to 9,999 people, data collection must begin no later than July 1, 2003. For systems serving fewer than 500 people, data collection must begin no later than January 1, 2004 (40 CFR Section 141.532). See Chapter 3 for more information on data collection. The CT_{calc} value derived for each disinfection segment will be used to calculate the inactivation ratio for each disinfection segment on a weekly basis.

4.2 WHAT IS CT?

CT simply stands for **concentration (C)** and **contact time (T)**. It is the result of multiplying the disinfectant residual concentration by the contact time. CT is a measure of disinfection effectiveness for the time that the water and disinfectant are in contact. "C" is the disinfectant residual concentration measured in mg/L at peak hourly flow and "T" is the time that the disinfectant is in contact with the water at peak hourly flow. The contact time (T) is measured from the point of disinfectant injection to a point where the residual is measured before the first customer (or the next disinfection application point) and is measured in minutes.

Equation 4-1
CT_{calc} (minutes-mg/L) = C x T
    C = Residual disinfectant concentration measured during peak hourly flow in mg/L.
    T = Time, measured in minutes, that the water is in contact with the disinfectant.

4.3 DETERMINING "C"

"C" is the residual disinfectant concentration measured during peak hourly flow in mg/L. The residual disinfectant concentration must be measured for each disinfection segment. In addition, the residual disinfectant concentration must be measured once per week on the same day of the week during peak hourly flow. See Chapter 3 for information on the residual disinfectant concentration.

4.4 DETERMINING "T"

Contact Time = T
(Sometimes referred to as T_{10})

The disinfectant contact time (T), also referred to as T_{10} in the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water* (EPA, 1991), is an estimate of the detention time within a basin or treatment unit at which 90 percent of the water passing through the unit is retained within the basin or treatment unit. T can be determined through a tracer study or estimated based on the theoretical detention time and baffling factor.

Before measuring or calculating T, a system may want to check its permits or other documentation that the State may have to see if a tracer study has been conduced for its facility. T can be determined based on the results of a tracer study. See Appendix E for more information on tracer studies.
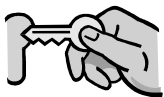
T must be calculated based on peak hourly flow.

The peak hourly flow rate is used to calculate the contact time within the treatment plant. Using the peak hourly flow rate for analysis provides a conservative value for the contact time.

The following steps may be used to calculate T for a treatment system:

- Define the disinfection segments in the system.

- Determine the peak hourly flow in the disinfection segment.

- Calculate the volume of each basin, pipe, or unit process in each disinfection segment (See Section 4.4.1).

- Calculate the theoretical detention time for each basin, pipe, or unit process (See Section 4.4.2).

- Determine the baffling factor (BF) of each basin, pipe, or unit process (See Section 4.4.3).

- Determine T for each basin, pipe, or unit process based on the theoretical detention time and baffling factor (See Section 4.4.4).

- Sum the Ts of each basin, pipe, or unit process for a total contact time for the disinfection segment.

Defining disinfection segments and measuring peak hourly flow have already been discussed in Chapters 2 and 3. The following sections discuss the remaining topics.

4.4.1 Volume

The volume of each basin, pipe, or unit process is used to calculate T. Since some treatment units, such as clearwells, can have fluctuating levels that affect volume, systems should consult the State on what volume should be used for the disinfection profile. Systems and States may want to consider the following options:

- Volumes can be based on the minimum volume that can occur in the treatment unit. This approach is the most conservative.

- Volumes can be based on the actual volume realized in the treatment unit during peak hourly flow if adequate information is available to identify the actual volume.

- Volumes can be based on the lowest volume realized in the treatment unit for that day.

Table 4-1 provides the equations used to find the volume of the specific sub-units or segments. See Appendix F for detailed examples of sub-units and volume equations.

Table 4-1: Volume Equations for Shapes

Volume Equations
See Appendix F for more information on volume calculations.

SHAPE	EXAMPLE OF UNIT WITH THIS SHAPE	VOLUME EQUATION
Cylindrical Pipes	Raw Water Pipe Plant Piping Finished Water Pipe	Length x Cross-sectional Area (πr^2)
Rectangular Basins	Rapid Mix, Flocculation, and Sedimentation Basins, Clearwells	Length x Width x Minimum Water Depth
Cylindrical Basins	Rapid Mix, Flocculation, and Sedimentation Basins, Clearwells	Minimum Water Depth x Cross-sectional Area (πr^2)
Rectangular Filters	Filtration	Surface Area of Filter x Depth of Water Above Filter Surface (Volume of water in the media pores may also be used.)

1 cubic foot = 7.48 gallons

4.4.2 Theoretical Detention Time

The theoretical detention time (TDT) is the time that the water is in a basin, pipe, or unit process assuming perfect plug flow. Perfect plug flow assumes no short-circuiting within the basin, pipe, or unit process. The TDT is calculated by dividing the volume based on low water level by the peak hourly flow (Equation 4-2).

Equation 4-2
TDT = V/Q

Equation 4-2
 TDT = V / Q
   TDT = Theoretical Detention Time, in minutes
   V = Volume based on low water level, in gallons
   Q = Peak hourly flow, in gpm

4.4.3 Baffling Factor

The T in each basin, pipe, or unit process is a function of configuration and baffling. The flow through a pipe is very different than the flow through an unbaffled basin (See Figure 4-1). The longest path a particle can take through a pipeline is not that different from the shortest path. In the case of an unbaffled basin, one particle may flow through directly from the inlet to the outlet. This short-circuiting particle will be in contact with the disinfectant for a relatively short time.

Plug Flow - The water travels through a basin, pipe, or unit process in such a fashion that the entire mass or volume is discharged at exactly the TDT of the unit and no short-circuiting occurs.

Short-circuiting - A hydraulic condition in a basin or unit process in which the actual flow time of water through the basin is less than the basin or unit process volume divided by the peak hourly flow.

Baffling Factor = 1.0

Baffling Factor = 0.1

Top: This pipe demonstrates a plug flow condition in which all of the material sent through the pipe discharges at the theoretical hydraulic detention time of the pipe.

Bottom: This unbaffled basin demonstrates short-circuiting in which some of the material entering the basin would come out almost immediately, while other material that enters at the same time will be detained for a longer period of time. Short-circuiting occurs in basins with poor baffling.

Figure 4-1: Baffling Characteristics of a Pipe and Clearwell

See Appendix G for more information on baffling factors.

Baffling factors (BF) have been developed that allow the contact time of a basin, pipe, or unit process to be estimated, based on the volume of and flow rate through a basin, pipe, or unit process. Baffling factors were developed based on numerous tracer studies of basins with different sizes and configurations. Table 4-2 and Appendix G provide a summary of theoretical baffling factors for various baffling conditions and basins.

Table 4-2: Baffling Factors

Baffling Condition	Baffling Factor	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles.
Average	0.5	Baffled inlet or outlet with some intra-basin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders.
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles.

Table 4-2
Baffling Factors

4.4.4 Calculate Contact Time

T can be calculated once the TDT and baffling factor are known (Equation 4-3).

Equation 4-3
T = TDT x BF

> **Equation 4-3**
> T = TDT x BF
>   T = Time, measured in minutes, that the water is in contact with the disinfectant.
>   TDT = Theoretical detention time, in minutes
>   BF = Baffling factor

Example 4-1: Determining "T"

Determine T for the conventional filtration system discussed in Example 3-1.

Diameter = 40 ft

Residual Monitoring
Point

Depth = 30 ft   Minimum Operating Level

To
Distribution
System

Chlorine
Injected

Peak Hourly
Flow = 347 gpm

Side View

To
Distribution
System

Peak Hourly
Flow = 347 gpm

Top View
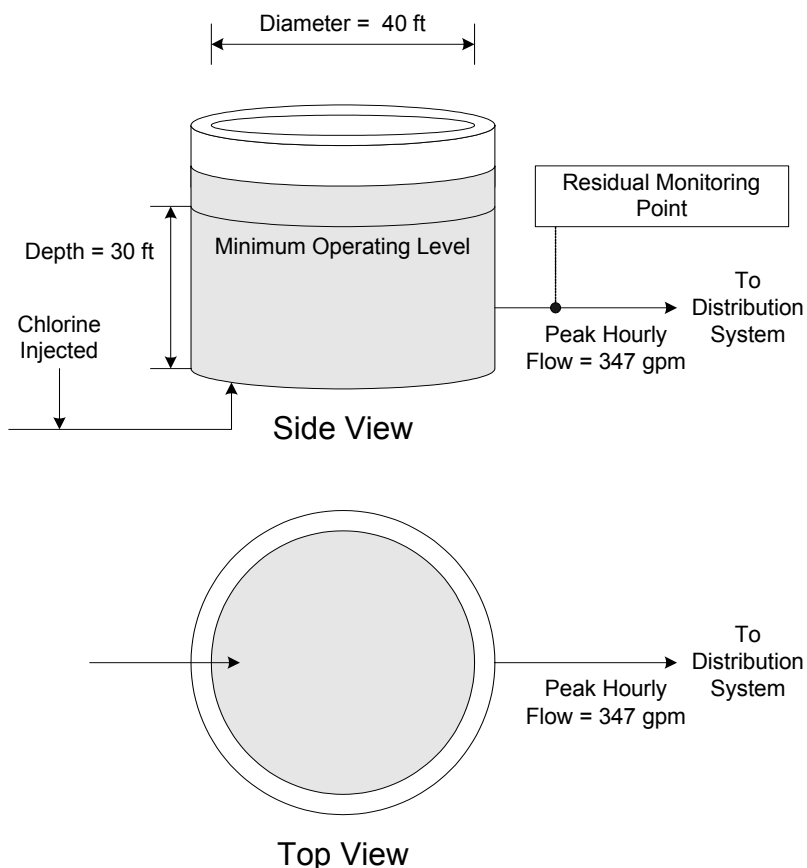
Step 1. Measure the physical dimensions of the clearwell.

Measure the inner tank diameter to obtain the volume of water in the clearwell rather than the volume of the tank itself.

Diameter = 40 ft

Measure the minimum operating depth in the clearwell to obtain a conservative estimate of the volume of water in the tank.

Minimum Water Depth = 30 ft

Example 4-1 continued

Step 2. Calculate the volume of the clearwell based on low water level.

From Table 4-1 the equation for calculating the volume of a cylindrical basin is:

Volume (V) = minimum water depth x cross-sectional area (πr^2)
where
π = 3.14
radius (r) = diameter / 2 = 40 ft / 2 =20 ft

V = 30 ft x 3.14 x (20 ft)^2 = 37,680 ft^3
V = 37,680 ft^3 x (7.48 gal / ft^3)
V = 282,000 gallons

The volume of the clearwell = 282,000 gallons

Note: More information on volume equations and calculations can be found in Appendix F.

Step 3. Calculate the theoretical detention time.

TDT = V / Q (Note: Q = peak hourly flow)   (Eq. 4-2)
TDT = 282,000 gal / 347 gpm
TDT = 813 minutes

The TDT in the clearwell is 813 minutes

Step 4. Determine the baffling factor for the clearwell.

From the diagram shown above there is no baffling in the clearwell. From Table 4-2, the baffling factor (BF) for an unbaffled basin is 0.1.

The baffling factor for the clearwell = 0.1

Step 5. Calculate the contact time of the disinfectant in the clearwell.

Contact Time = TDT x BF   (Eq. 4-3)
T = 813 min x 0.1
T = 81.3 minutes

The contact time in the clearwell = 81.3 minutes

Worksheet #1 in Appendix C can be used to record data and calculate contact time. The worksheet excerpt on the next page demonstrates how data may be recorded from this example and previous examples using Worksheet #1 in Appendix C.

Example 4-1 continued

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: _January_   Year: _2004_   PWSID: _AA1234567_   System/Water Source: _XYZ Water Plant_

Disinfectant Type: _Free Chlorine_   Prepared by: _Joe Operator_
Profile Type (check one): _X_ *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: _Clearwell/1st_

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT_Calc = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.8	6	0.5	347	282,000	813	0.1	81.3				
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

4.5 Calculate CT$_{calc}$

To calculate CT$_{calc}$, a system must monitor the residual disinfectant concentration and the amount of time that the water is in contact with the disinfectant. A system that is required to complete a disinfection profile must determine CT$_{calc}$ values once per week, on the same day of the week, for one year.

The disinfection effectiveness for the time that the water and disinfectant are in contact is calculated as follows:

Equation 4-1
$CT_{calc} = C \times T$

> **Equation 4-1**
> CT_{calc} (minutes-mg/L) = C x T
>   C = Residual disinfectant concentration measured during peak hourly flow in mg/L.
>   T = Time, measured in minutes, that the water is in contact with the disinfectant.

Example 4-2 demonstrates how to determine CT_{calc} for one disinfection segment. If more than one disinfectant is used or if residual disinfectants are measured in more than one location, then CT_{calc} must be calculated for each disinfection segment. See the examples in Appendix D for more illustrations of calculating CT_{calc} under different operating conditions.

Example 4-2: Calculate CT$_{calc}$

Calculate CT_{calc} for the conventional filtration system in the previous examples.

One Disinfection Segment:
One injection point, one monitoring point
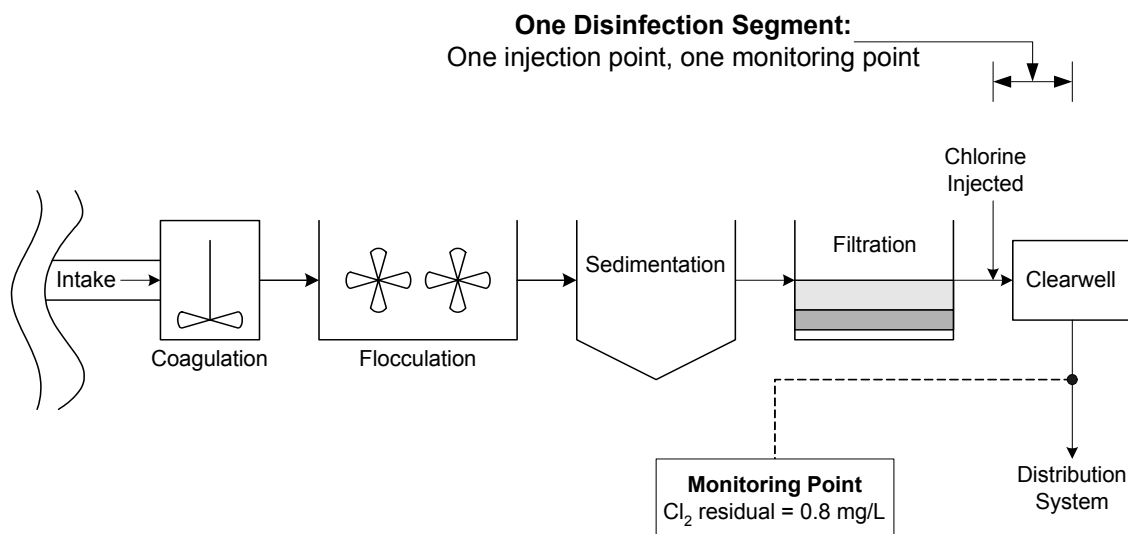
Step 1. Determine "C".

From example 3-1, **C = 0.8 mg/L**

Step 2. Determine "T".

From example 4-1, **T = 81.3 minutes**

Step 3. Calculate CT$_{calc}$.

CT = C x T
CT = 0.8 mg/L x 81.3 minutes
CT = 65.0 min-mg/L

CT$_{calc}$ = 65.0 min-mg/L

Worksheet #1 in Appendix C can be used to record data and calculate CT_{calc}. The worksheet excerpt below demonstrates how to record the data from this example and previous examples using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year: <u>2004</u>   PWSID: <u>AA1234567</u>   System/Water Source: <u>XYZ Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: <u>Joe Operator</u>
Profile Type (check one): <u>X</u> *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: <u>Clearwell/1st</u>

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT_Calc = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.8	6	0.5	347	282,000	813	0.1	81.3	65.0			
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

4.6   STEPS COMPLETED
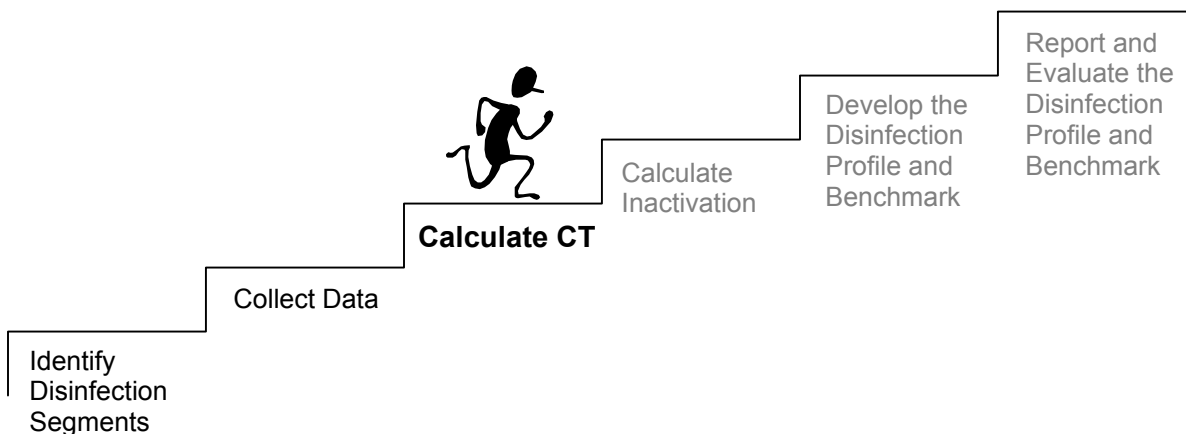
4.7   NEXT STEP

In addition to CT_{calc}, CT required must also be determined to calculate log inactivation. Chapter 5 describes how to determine CT required and calculate log inactivation.

4.8   REFERENCES

EPA. 1991. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water*. Washington, D.C.

5. CALCULATING INACTIVATION

In this Chapter:
- Log Reduction
- Determining CT Required
- Calculating Actual Log Inactivation for One Disinfection Segment
- Calculating Actual Log Inactivation for Multiple Disinfection Segments
- Steps Completed
- Next Step

1-log reduction = 90%
2-log reduction = 99%
3-log reduction = 99.9%
4-log reduction = 99.99%
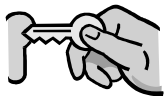
A spreadsheet (in Microsoft® Excel) has been developed that can be used by systems to calculate log inactivations. The spreadsheet is available on EPA's website at http://www.epa.gov/safe-water/mdbp/lt1eswtr.html.

5.1 INTRODUCTION

In order to develop a disinfection profile, the *Giardia* log inactivation must be calculated. The log inactivation of viruses must also be calculated if the system uses ozone, chloramines, or chlorine dioxide for primary disinfection. Ozone, chloramines, and chlorine dioxide are not as effective for inactivating viruses as for inactivating *Giardia*, and systems must make sure the appropriate virus inactivation is achieved. To determine log inactivation achieved through disinfection, a series of calculations are completed. First, CT_{calc} is determined (See Chapter 4). Then CT_{calc} is related to the required CT using CT tables (See Section 5.3). The CT required for a desired log inactivation is dependent upon pH (if chlorine is used), temperature, and residual disinfectant concentration (for chlorine). Individual CT tables are used for each type of disinfectant because the effectiveness of different disinfectants varies with each type of microorganism. For this reason, separate CT tables have been developed for chlorine, chlorine dioxide, ozone, and chloramines for both *Giardia* and viruses (See Appendix B).

5.2 LOG REDUCTION

The concept of log reduction (removal and inactivation) is used extensively in discussions of compliance with microbiological requirements. The term refers to logarithmic theory. Essentially, in this context, log reduction relates to the percentage of microorganisms physically removed or inactivated by a given process. One log reduction means that 90% of the microorganisms are removed or inactivated. Two log corresponds to 99%, three log corresponds to 99.9% and four log corresponds to 99.99%. The removal or inactivation "log number" coincides with the number of nines in the percentage reduction. This chapter will discuss log inactivation achieved through disinfection only; however, it should be remembered that when determining the total system reduction, the physical log removal is added to the log inactivation through disinfection for total reduction of microorganisms (See Chapter 7).

5.3 DETERMINING CT REQUIRED

After determining CT_{calc} (See Chapter 4) based on system operating parameters and configuration, CT tables are used to determine the required CT value for a certain level of inactivation. The CT tables in Appendix B give CT values that achieve a 3-log inactivation of *Giardia* and viruses, as a function of disinfectant type, temperature, pH and residual disinfectant concentration. The following guidelines can be used to obtain the required CT value from the CT tables:

- Find the appropriate table based on the disinfectant used.

- Find the appropriate table based on the microorganism of concern (*Giardia* or viruses).

- Find the appropriate portion of the table (for chlorine) or column based on measured temperature.

- Find the appropriate column (for chlorine) based on the measured pH. Systems should contact the State if the pH value is not included in the CT tables in Appendix B.

- Find the appropriate row based on the measured disinfectant residual (for chlorine only).

- Identify the CT value based on the above information.

The CT tables in Appendix B for chlorine are based on pH. The CT tables in Appendix B for *Giardia* inactivation by chloramines and virus inactivation by chlorine dioxide also list a range for pH. Although systems are not required to monitor the pH for chloramines and chlorine dioxide, systems should ensure that the pH falls between the range of 6-9 when this pH range is specified in the CT tables.

The following sections discuss how to obtain 3-log CT required for *Giardia* inactivation ($CT_{99.9}$) and 4-log CT required for virus inactivation ($CT_{99.99}$).

$CT_{99.9}$ for *Giardia* = 3-log inactivation

$CT_{99.99}$ for viruses = 4-log inactivation

If the temperature, pH, or residual disinfectant concentration falls between or outside the values listed in the columns or rows on the table, systems should contact the State for the appropriate method to determine CT required. Appendix H presents two different interpolation methods.

5.3.1 CT$_{99.9}$ for *Giardia*

The CT table for inactivation of *Giardia* by chloramines (Table B-7) lists values between the pH range 6 to 9.

All surface water systems or GWUDI systems are required to achieve 3-log (99.9%) reduction of *Giardia* through removal (filtration) and/or inactivation (disinfection) (See 40 CFR 141.70(a)(1)). States generally grant log removal credits for filtration which typically vary depending on the treatment process (such as conventional, direct, or alternative filtration). For unfiltered systems, all three logs must be achieved through disinfection. For filtered systems, refer to Table 7-2 for typical log removal credits and resulting inactivation values that must be achieved by disinfection. Inactivation through disinfection can be achieved by one disinfectant or a combination of disinfectants. The method used to calculate log inactivation under the LT1ESWTR requires that the CT$_{99.9}$ value for *Giardia* be determined. Example 5-1 illustrates how to obtain CT$_{99.9}$.

Example 5-1: Determining CT$_{99.9}$

The conventional filtration system discussed in Examples 3-1, 4-1, and 4-2 uses chlorine disinfectant only; therefore the system only needs to calculate CT$_{99.9}$ for *Giardia* because chlorine is significantly more effective against viruses than *Giardia*. Find the required CT to achieve 3-log inactivation of *Giardia*, or CT$_{99.9}$.

One Disinfection Segment:
One injection point, one monitoring point

Chlorine Injected

Filtration

Intake → Coagulation → Flocculation → Sedimentation → Filtration → Clearwell → Distribution System

Monitoring Point
Cl$_2$ residual = 0.8 mg/L
Temperature = 0.5 °C
pH = 6
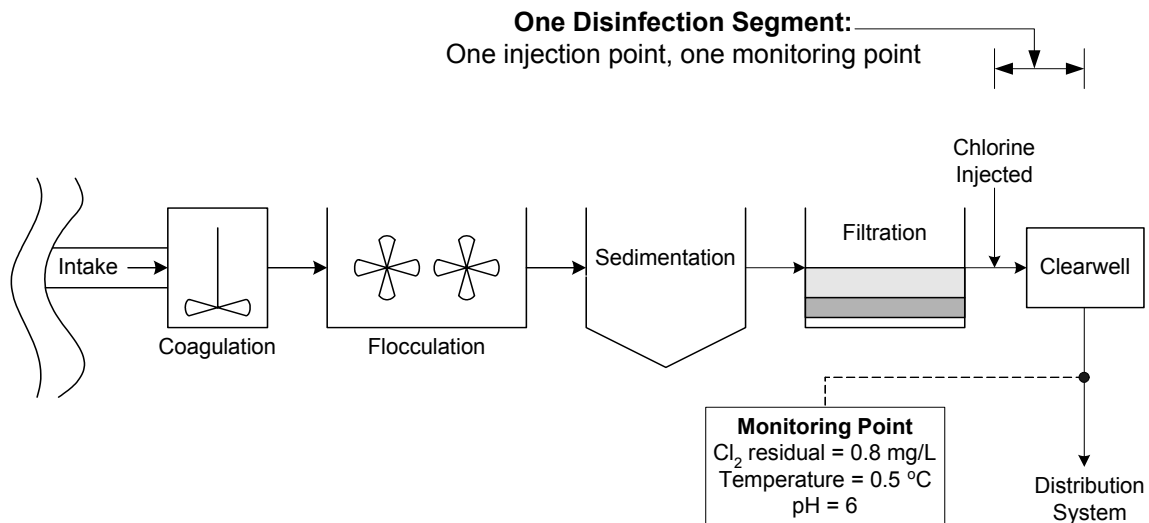
Example 5-1 continued

Step 1. Gather required data during peak hourly flow.

>   **Water temperature = 0.5 °C**
>   **Chlorine residual = 0.8 mg/L**
>   **pH = 6.0**

Step 2. Locate appropriate CT table.

The table for 3-log inactivation of *Giardia* by free chlorine is Table B-1 in Appendix B.

Step 3. Identify the appropriate portion of the table based on operating conditions and 3-log **Giardia** *inactivation.*

The first section of the table is for temperatures less than or equal to 0.5 $^{\circ}$C. The first column in that section is for pHs less than or equal to 6.0. The disinfectant residual of 0.8 mg/L is found in the third row down on the chart. The relevant portion of Table B-1 is reprinted below.

Excerpt from Table B-1:

CT values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine (0.5 °C portion of table for 0.4 to 1.2 mg/L)

Chlorine Concentration (mg/L)	Temperature <= 0.5 $^{\circ}$C						
	pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	137	163	195	237	277	329	390
0.6	141	169	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451

Step 4. Obtain CT$_{99.9}$ value.

From this chart, the value of CT for 3-log inactivation at 0.8 mg/L and pH of 6 is **145 min-mg/L.**

>   **CT$_{99.9}$ for *Giardia* = 145 min-mg/L**

Worksheet #1 in Appendix C can be used to record data needed to determine CT$_{99.9}$ and to record the value of CT$_{99.9}$. The worksheet excerpt on the next page demonstrates how to record the data from this example and previous examples using Worksheet #1 in Appendix C.

Example 5-1 continued

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: January_____ Year: 2004_____ PWSID: AA1234567___ System/Water Source: XYZ Water Plant_____

Disinfectant Type: Free Chlorine____ Prepared by: Joe Operator_____
Profile Type (check one): __X__ *Giardia* _____Viruses

Disinfection Segment/Sequence of Application: Clearwell/1st_____

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT_{Calc} = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.8	6	0.5	347	282,000	813	0.1	81.3	65.0	145		
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

5.3.2 $CT_{99.99}$ for Viruses

The CT table for inactivation of viruses by chlorine dioxide (Table B-4) lists values between the pH range 6 to 9.

All surface water systems or GWUDI systems are required to achieve 4-log (99.99%) reduction of viruses through removal (filtration) and/or inactivation (disinfection) (See 40 CFR 141.70(a)(2)). States generally grant log removal credits for filtration which typically vary depending on the treatment process (such as conventional, direct, or alternative filtration). For unfiltered systems, all four logs must be achieved through disinfection. One method used to calculate log inactivation uses the $CT_{99.99}$ value for viruses. Virus inactivation must be determined if chloramines, chlorine dioxide, or ozone are used for primary disinfection (See 40 CFR 141.535). Example D-3 in Appendix D illustrates a method for obtaining $CT_{99.99}$ for a system using ozone.

5.4 CALCULATING ACTUAL LOG INACTIVATION FOR ONE DISINFECTION SEGMENT

40 CFR Section 141.534

Actual log inactivation can be calculated as a ratio of the CT_{calc} value achieved by the system to the CT value required for 3-log inactivation of *Giardia* or 4-log inactivation of viruses.

Equation 5-1

The following equation must be used to calculate *Giardia* log inactivation for one disinfection segment:

Equation 5-1

Actual Log Inactivation of *Giardia* = 3 x (CT$_{calc}$ / CT$_{99.9}$)

Example 5-2 shows how a system may calculate the *Giardia* log inactivation achieved in a system with one disinfection segment.

Example 5-2: Determine Actual Log Inactivation for *Giardia*

The conventional filtration system discussed in Examples 3-1, 4-1, 4-2 and 5-1 uses chlorine disinfectant only; therefore the system only needs to calculate actual *Giardia* log inactivation because chlorine is significantly more effective against viruses than *Giardia*. Determine the actual *Giardia* log inactivation achieved by the system.

Step 1. Determine CT$_{calc}$ and CT$_{99.9}$ for the disinfection segment.

The following table summarizes the values determined for CT$_{calc}$ and CT$_{99.9}$:

Disinfection Segment	CT$_{calc}$ min-mg/L	CT$_{99.9}$ for *Giardia* min-mg/L
1-Chlorine	65.0	145

Step 2. Calculate the inactivation ratio for the clearwell.

Inactivation Ratio = CT$_{calc}$ / CT$_{99.9}$
Inactivation Ratio = 65.0 / 145
Inactivation Ratio = 0.448

Step 3. Calculate Giardia log inactivation for the clearwell.

Giardia log inactivation = 3 x (CT$_{calc}$ / CT$_{99.9}$)
Giardia log inactivation = 3 x 0.448
***Giardia* log inactivation = 1.34**

Refer to Chapter 7 for more information on interpreting log inactivation values.

Example 5-2 continued

Worksheet #1 in Appendix C can be used to record data and calculate log inactivation. The worksheet excerpt below demonstrates how data may be recorded from this example and previous examples using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year: <u>2004</u>   PWSID: <u>AA1234567</u>   System/Water Source: <u>XYZ Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: <u>Joe Operator</u>
Profile Type (check one):   <u>X</u> *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: Clearwell/1st

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT$_{Calc}$ = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.8	6	0.5	347	282,000	813	0.1	81.3	65.0	145	0.448	1.34
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

Equation 5-2
Check with the State on the approved method to calculate virus inactivation.

Systems should check with their State to determine the appropriate method for calculating virus inactivation. The following equation was used for the examples presented in this document:

> **Equation 5-2**
> Actual Log Inactivation of Viruses = 4 x (CT$_{calc}$ / CT$_{99.99}$)

Additional examples of calculating the actual log inactivation of *Giardia* and viruses are contained in Appendix D**. A spreadsheet has also been developed that can be used by systems to calculate log inactivations. The spreadsheet is available on EPA's website (www.epa.gov/safewater/mdbp/lt1eswtr.html).**

5.5 CALCULATING ACTUAL LOG INACTIVATION FOR MULTIPLE DISINFECTION SEGMENTS

Actual log inactivation for a system with more than one disinfection segment is calculated as a sum of the ratios of the CT_{calc} value achieved by each disinfection segment to the CT value required for 3-log inactivation of *Giardia* or 4-log inactivation of viruses in each disinfection segment.

The following equation must be used to calculate *Giardia* log inactivation for a system with multiple disinfection segments:

Equation 5-3

Σ = Sum of.

Systems must sum the $CT_{calc} / CT_{99.9}$ inactivation ratios for each disinfection segment if the system has multiple disinfection segments.

> **Equation 5-3**
>
> Actual Log Inactivation of *Giardia* = 3 x Σ ($CT_{calc} / CT_{99.9}$)

Example 5-3 shows how a system may use the worksheets in Appendix C to calculate the *Giardia* log inactivation achieved in a system with multiple disinfection segments.

Example 5-3: Determine Total Log Inactivation for *Giardia*

The conventional filtration system discussed in Example D-2 in Appendix D uses chlorine as a pre-disinfectant and a primary disinfectant and uses chloramines as a secondary disinfectant. Determine the total *Giardia* log inactivation achieved by the system.

The worksheets in Appendix C can be used to record data and calculate log inactivation.

The following table summarizes the calculations for each unit process in Disinfection Segment 1 in Example D-2.

Unit Process	Volume (gal)	Peak Hourly Flow (gpm)	TDT (min)	BF[*]	Contact Time (min)
Coagulation	24,000	5,000	4.8	0.1	0.48
Flocculation	80,000	5,000	16	0.1	1.6
Sedimentation	100,000	5,000	20	0.5	10
Filtration	45,000	5,000	9	0.7	6.3
Total:	**249,000**				**18.4**

* See Appendix G for baffling factors.

Example 5-3 continued

The worksheet excerpt below demonstrates how a system may record the data from Disinfection Segment 1 in Example D-2 using Worksheet #1 in Appendix C. For this example, Worksheet #1 should be copied so the data from each disinfection segment can be entered.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year: <u>2004</u>   PWSID: <u>AA7654321</u>   System/Water Source: <u>ABC Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: <u>Jon Operator</u>
Profile Type (check one): <u>X</u> *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: <u>Coagulation, Flocculation, Sedimentation, Filtration/1st</u>

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT$_{Calc}$ = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	1.0	7.5	10	5,000	249,000	**	**	18.4	18.4	134	0.137	
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.
**See the previous table showing details of each unit process for theoretical detention times and baffling factors.

The worksheet excerpt below demonstrates how a system may record the data from Disinfection Segment 2 in Example D-2 using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year: <u>2004</u>   PWSID: <u>AA7654321</u>   System/Water Source: <u>ABC Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: <u>Jon Operator</u>
Profile Type (check one): <u>X</u> *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: <u>Clearwell/2nd</u>

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT$_{Calc}$ = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	1.2	7.5	10	5,000	300,000	60	0.7	42	50	137	0.365	
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

Example 5-3 continued

The worksheet excerpt below demonstrates how a system may record the data from Disinfection Segment 3 in Example D-2 using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: January   Year: 2004   PWSID: AA7654321   System/Water Source: ABC Water Plant

Disinfectant Type: Chloramine   Prepared by: Jon Operator
Profile Type (check one): X *Giardia*   Viruses

Disinfection Segment/Sequence of Application: Transmission Pipe/3rd

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT_{Calc} = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.6	N/A	10	5,000	31,000	6.2	1.0	6.2	3.7	1,850	0.002	
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

The worksheet excerpt below demonstrates how a system may determine total *Giardia* log inactivation for the system in Example D-2 using Worksheet #2 in Appendix C.

WORKSHEET #2
TOTAL LOG INACTIVATION DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: January   Year: 2004   PWSID: AA7654321

System/Water Source: ABC Water Plant   Prepared by: Jon Operator

Disinfectant Type: Chlorine/Chloramine
Profile Type (check one): X *Giardia*   Viruses

Week #	Disinfection Segment 1	Disinfection Segment 2	Disinfection Segment 3	Disinfection Segment 4	Disinfection Segment 5	Sum of Inactivation Ratios	Total Log Inactivation[1]
1	0.137	0.365	0.002			0.504	1.51
2							
3							
4							
5							
6							

[1]*Giardia*: Log Inactivation = 3 x Sum of Inactivation Ratios
Viruses: Log Inactivation = 4 x Sum of Inactivation Ratios (or a method approved by the State)

Refer to Chapter 7 for more information on interpreting log inactivation values.

Equation 5-4

Σ = Sum of.

Systems must sum the $CT_{calc} / CT_{99.99}$ inactivation ratios for each disinfection segment if the system has multiple disinfection segments.

Check with the State on the approved method to calculate virus inactivation.

Systems should check with their State to determine the appropriate method to use for calculating virus inactivation. The following equation was used for the examples presented in Appendix D of this document:

Equation 5-4

Actual Log Inactivation of Viruses = 4 x Σ ($CT_{calc} / CT_{99.99}$)

Example D-3 in Appendix D presents one method for determining virus log inactivation for a system using ozone.

5.6 STEPS COMPLETED
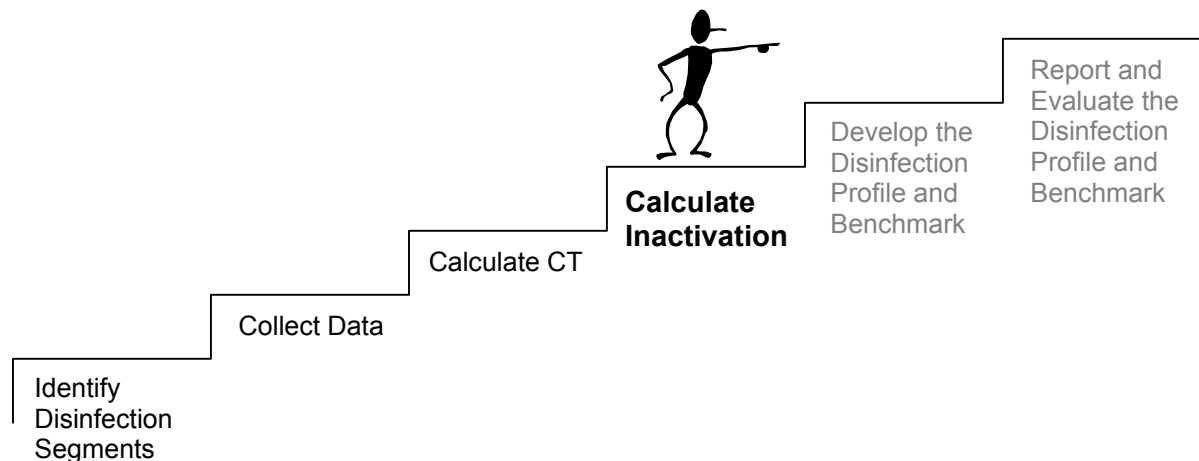
5.7 NEXT STEP

Once a system has determined log inactivation values once per week for a full year, then a disinfection profile and benchmark (if required) can be developed. Chapter 6 presents information on how to develop the disinfection profile and calculate a benchmark.

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6. DEVELOPING THE DISINFECTION PROFILE AND BENCHMARK

In this Chapter:

- Constructing a Disinfection Profile
- The Disinfection Benchmark
- Significant Changes to Disinfection Practices
- Benchmark Calculations
- Steps Completed
- Next Step

40 CFR Section 141.534 Systems that use chlorine as a disinfectant must create a disinfection profile for *Giardia* only.

40 CFR Section 141.535 Systems that use chloramines, chlorine dioxide, or ozone for primary disinfection must create a disinfection profile for *Giardia* and viruses. The method used to calculate virus inactivation must be approved by the State.

6.1 INTRODUCTION

Once the log inactivation has been calculated, a disinfection profile can be developed. A **disinfection profile** is a graphical representation of a system's level of *Giardia* or virus inactivation measured during the course of a year (Figure 6-1 provides an example disinfection profile). The disinfection profile is the log inactivation (of *Giardia* or viruses) graphed as a function of time. It can be used as a tool in the decision making process for a system's disinfection practices.

For systems that use chlorine as a disinfectant, *Giardia* is the more difficult organism to treat; therefore it is the limiting parameter and the only pathogen for which a disinfection profile is required. Viruses may be the limiting parameter for systems that use chloramines, chlorine dioxide, or ozone. Therefore, systems that use these disinfectants for primary disinfection must create a disinfection profile for both *Giardia* and viruses. **The method used to calculate viral log inactivations must be approved by the State.**

If a system was required to develop a disinfection profile and decides to make a significant change to disinfection practices, then a disinfection benchmark must be calculated. The disinfection benchmark is the lowest monthly average log inactivation. The disinfection benchmark will be used by both the system and the State to evaluate proposed modifications to disinfection practices.

40 CFR Section 141.536

Example Disinfection
Profile

6.2 CONSTRUCTING A DISINFECTION PROFILE

After log inactivation values have been calculated once each
week for one year (using the method presented in Section 5.4),
the system must produce a disinfection profile. A disinfection
profile is a graph of log inactivation data. The log inactivations
may be plotted along the vertical axis of a graph with the
corresponding weeks of the year plotted along the horizontal
axis, as shown in Figure 6-1. Systems are required to retain the
disinfection profile in graphic form and it must be available for
review by the State as part of a sanitary survey. Example 6-1
demonstrates how to create a disinfection profile.

**Figure 6-1. Example of a Completed Disinfection
Profile**
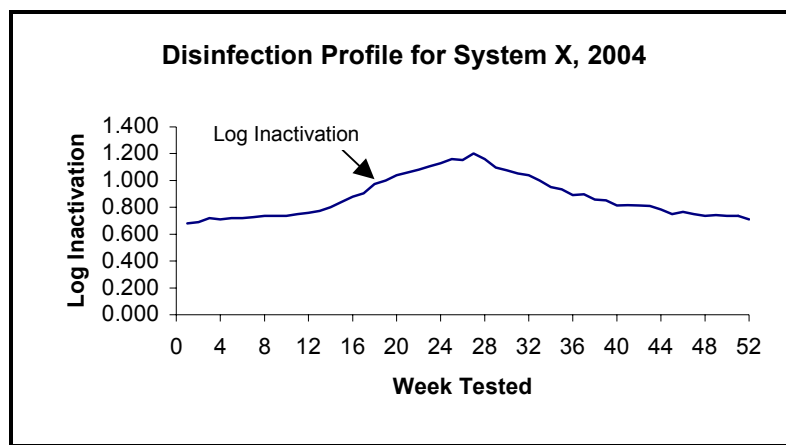
Example 6-1: Disinfection Profile for *Giardia*

Create a disinfection profile for *Giardia* for the conventional filtration system that was discussed in Examples 3-1, 4-1, 4-2, 5-1, and 5-2..

Step 1. Calculate the* Giardia *log inactivations once per week on the same day of the week for one year.

The table below shows the *Giardia* log inactivations that were calculated each week for one year using the methods presented in Section 5.4 and Example 5-2. This information can also be obtained from the first and last columns of Worksheet #1 in Appendix C for systems with one disinfection segment or Worksheet #2 in Appendix C for systems with multiple disinfection segments.

Month	Week	Log Inact.		Month	Week	Log Inact.
JAN	1	1.34		JULY	27	1.86
	2	1.35			28	1.82
	3	1.38			29	1.76
	4	1.37			30	1.74
	5	1.38			31	1.71
FEB	6	1.38		AUG	32	1.70
	7	1.39			33	1.66
	8	1.40			34	1.61
	9	1.40			35	1.60
MARCH	10	1.40		SEP	36	1.55
	11	1.41			37	1.56
	12	1.42			38	1.52
	13	1.43			39	1.51
APRIL	14	1.46			40	1.47
	15	1.50		OCT	41	1.48
	16	1.54			42	1.47
	17	1.57			43	1.47
	18	1.64			44	1.45
MAY	19	1.66		NOV	45	1.41
	20	1.70			46	1.43
	21	1.72			47	1.41
	22	1.74			48	1.40
JUNE	23	1.77		DEC	49	1.40
	24	1.79			50	1.40
	25	1.82			51	1.40
	26	1.81			52	1.37

Example 6-1 continued

Step 2. Plot the disinfection profile.

The log inactivations are plotted along the vertical axis with the corresponding weeks of the year plotted along the horizontal axis.   The log inactivation value for week 1 (1.34) is plotted on the vertical axis at a point corresponding to week 1 on the horizontal axis, as shown below. The log inactivation value for week 2 (1.35) is plotted on the horizontal axis at a point corresponding to week 2 on the horizontal axis. The log inactivation value for week 3 (1.38) is plotted on the horizontal axis at a point corresponding to week 3 on the horizontal axis. After the points are plotted, lines are drawn to connect the points in order by the week tested.
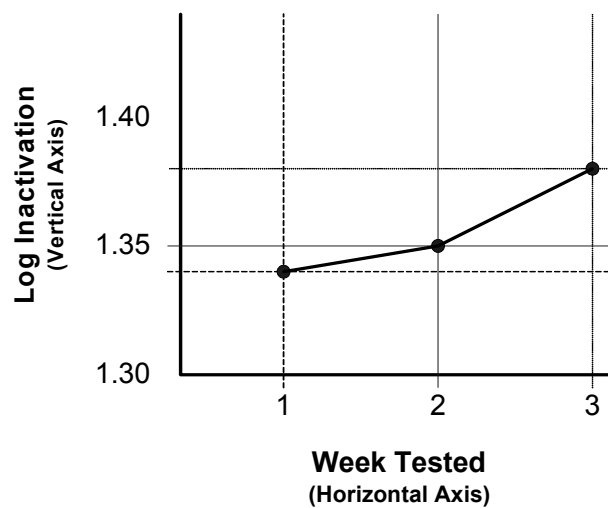
Continue to plot the points for each week until all 52 weeks have been plotted. The completed disinfection profile is shown below.
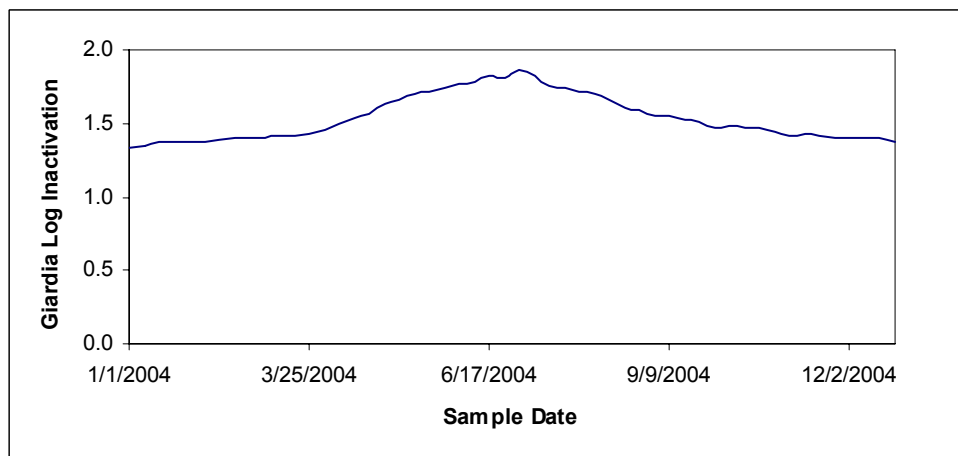
Once a disinfection profile has been completed for a system, the system will have all of the data required to calculate a benchmark (which is necessary if the system contemplates making a significant change to its disinfection practices). The next sections discuss what a benchmark is and how it is calculated.

6.3 THE DISINFECTION BENCHMARK

40 CFR Section 141.540

The LT1ESWTR requires systems to develop a disinfection benchmark if the system is required to create a disinfection profile and decides to make a significant change to disinfection practices. The system must consult with the State for approval prior to making a significant change to disinfection practices (See Section 6.4 for a description of significant changes). Systems may be considering disinfection modifications for compliance with the Stage 1 DBPR requirements or for other reasons. The disinfection profile and benchmark information will allow the State to assess appropriate modifications to disinfection practices, as necessary. As explained in Chapter 1, benchmarking is used to characterize the minimum level of *Giardia*, and in some cases, virus log inactivations that are provided under current disinfection practices. The benchmark calculated under existing conditions can be compared to the benchmark calculated under the proposed modifications to ensure that changes to disinfection practices do not result in inactivation levels lower than the required inactivation values without appropriate State consultation and review.

System must consult the State prior to making modifications to disinfection practices.

A benchmark is required if **both** of the following criteria apply:

- A disinfection profile is required;

  AND,

- The system decides to make a significant change(s) to disinfection practices.

Systems that do not use chloramines, ozone, or chlorine dioxide as primary disinfection will calculate a profile and benchmark for *Giardia* only. Systems that use chloramines, ozone, or chlorine dioxide for primary disinfection must also calculate a profile and benchmark based on virus inactivation in addition to those for *Giardia* inactivation. Virus inactivation must be determined for these systems to address the possibility of reduced inactivation for viruses when using an alternative disinfectant.

40 CFR Section 141.541

40 CFR Section 141.543

Equation 6-1
Monthly Average Log
Inactivation

6.4 SIGNIFICANT CHANGES TO DISINFECTION PRACTICES

The LT1ESWTR describes four types of significant modifications to disinfection practices:

- Changes to the point of disinfection;

- Changes to the disinfectant(s) used in the treatment plant;

- Changes to the disinfection process; or,

- Any other modification identified by the State.

Systems may consider one or more of the above-mentioned modifications to comply with Stage 1 DBPR. These modifications will require the system to calculate its benchmark. The benchmark will be used for discussion with the State on disinfection modifications. The significant modifications are discussed in more detail in Chapter 7.

6.5 BENCHMARK CALCULATIONS

A disinfection benchmark is calculated using the following steps:

- Complete a disinfection profile that includes the calculation of log inactivation of *Giardia* and viruses (if required) for each week of the profile.

- Compute the average log inactivation for each calendar month of the profile by averaging the weekly log inactivation values for each month (See Equation 6-1).

Equation 6-1

$$\text{Monthly Average Log Inactivation} = \frac{\text{Sum of Weekly Log Inactivation Values}}{\text{Number of Weekly Values per Month}}$$

- Select the month with the lowest average log inactivation for the 12-month period. This value is the benchmark.

Example 6-2 demonstrates how to calculate the disinfection benchmark.

Example 6-2: Calculating a Benchmark

Calculate the disinfection benchmark for the conventional filtration system discussed in Examples 3-1, 4-1, 4-2, 5-1, 5-2, and 6-1.

Step 1. Calculate weekly Giardia log inactivations.

This step was completed in Example 6-1. The data is summarized below:

Month	Week	Log Inact.		Month	Week	Log Inact.
JAN	1	1.34		JULY	27	1.86
	2	1.35			28	1.82
	3	1.38			29	1.76
	4	1.37			30	1.74
	5	1.38			31	1.71
FEB	6	1.38		AUG	32	1.70
	7	1.39			33	1.66
	8	1.40			34	1.61
	9	1.40			35	1.60
MARCH	10	1.40		SEP	36	1.55
	11	1.41			37	1.56
	12	1.42			38	1.52
	13	1.43			39	1.51
APRIL	14	1.46			40	1.47
	15	1.50		OCT	41	1.48
	16	1.54			42	1.47
	17	1.57			43	1.47
	18	1.64			44	1.45
MAY	19	1.66		NOV	45	1.41
	20	1.70			46	1.43
	21	1.72			47	1.41
	22	1.74			48	1.40
JUNE	23	1.77		DEC	49	1.40
	24	1.79			50	1.40
	25	1.82			51	1.40
	26	1.81			52	1.37

Example 6-2 continued

Step 2. Calculate the monthly average log inactivation for each month.

Begin by averaging January's inactivations:

Average log inactivation for January = (Sum of Weekly Log Inactivation Values)
                                        (Number of Weekly values in Month)

$$= \frac{1.34 + 1.35 + 1.38 + 1.37 + 1.38}{5 \text{ values}}$$

$$= (6.82) / (5) = \textbf{1.36}$$

Continue this process for each month. The following are the results for the Example system:

January	**1.36**	July	1.78
February	1.39	August	1.64
March	1.41	September	1.52
April	1.54	October	1.47
May	1.71	November	1.41
June	1.80	December	1.39

Step 3. Identify the month with the lowest monthly average log inactivation. The log inactivation for this month is the disinfection benchmark.

The month with the lowest monthly average log inactivation is January, with a value of 1.36.

The benchmark is 1.36.

6.6 STEPS COMPLETED

Identify
Disinfection
Segments

Collect Data

Calculate CT

Calculate
Inactivation

**Develop the
Disinfection
Profile and
Benchmark**

Report and
Evaluate the
Disinfection
Profile and
Benchmark
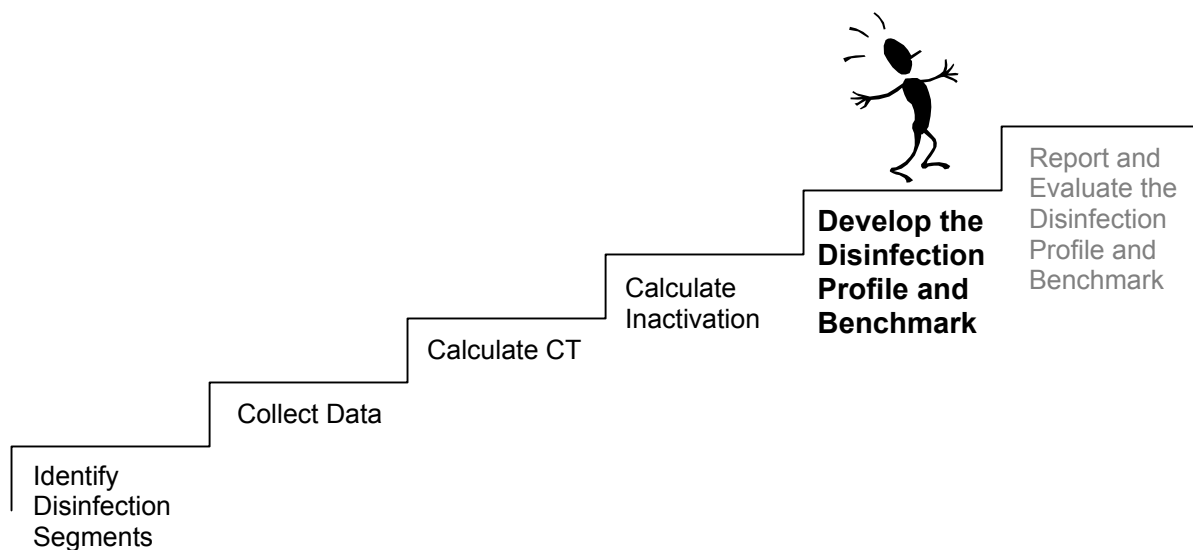
6.6 NEXT STEP

By calculating the benchmark, the system has identified its lowest monthly average inactivation value. This benchmark is used as a guide when evaluating disinfection practice modifications. Chapter 7 provides information on how to evaluate disinfection practice modifications.

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7. EVALUATING DISINFECTION PRACTICE MODIFICATIONS

In this Chapter:
- System Reporting Requirements
- Simultaneous Compliance
- How the State will Use the Benchmark
- Steps Completed

Systems must consult the State prior to making modifications to disinfection practices.

7.1 INTRODUCTION

The benchmark is a system's lowest monthly average *Giardia* (or virus) inactivation based on the disinfection profile. The benchmark must be calculated if a system is required to develop a disinfection profile and decides to make a significant modification to disinfection practices. The benchmark will help in evaluating alternatives to the current disinfection practices. Remember, a system must reliably and consistently provide the necessary log inactivation through disinfection to achieve adequate *Giardia* and virus log reduction as required by the SWTR (See Table 7-1). Table 7-2 provides typical removal credits and inactivation requirements for different processes. Systems should check with the State on the specific removal credits and inactivation requirements since Table 7-2 contains typical values.

If a benchmark value is less than the required log inactivation for disinfection, then the system will probably need to modify disinfection practices, such as increasing the amount of disinfectant or the contact time. Increasing the amount of disinfectant will probably require the system to evaluate disinfection byproducts more closely.

If the benchmark is greater than the required inactivation in Table 7-2 (or as required by the State), the system can consider decreasing the amount of disinfectant added, contact time, or altering other disinfection practices. Systems must consult the State for approval prior to making a significant change to their disinfection practices. The State will work with the system to determine if the change is significant and whether it triggers any additional requirements under LT1ESWTR.
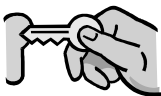
Microbial removal and inactivation requirements.

Table 7-1: Removal and Inactivation Requirements

Microorganism	**Required Log Reduction**	**Treatment**
Giardia	3-log (99.9%)	Removal and/or Inactivation
Viruses	4-log (99.99%)	Removal and/or Inactivation
Cryptosporidium	2-log (99%)	Removal

Table 7-2: Typical Removal Credits and Inactivation Requirements for Various Treatment Technologies

Process	**Typical Log Removal Credits**		**Resulting Disinfection Log Inactivation Requirements**	
	Giardia	**Viruses**	*Giardia*	**Viruses**
Conventional Treatment	2.5	2.0	0.5	2.0
Direct Filtration	2.0	1.0	1.0	3.0
Slow Sand Filtration	2.0	2.0	1.0	2.0
Diatomaceous Earth Filtration	2.0	1.0	1.0	3.0
Alternative (membranes, bag filters, cartridges)	*	*	*	*
Unfiltered	0	0	3.0	4.0

* Systems must demonstrate to the State by pilot study or other means that the alternative filtration technology provides the required log removal and inactivation shown in Table 7-1.

40 CFR Section 141.542

7.2 SYSTEM REPORTING REQUIREMENTS

A system that is considering a significant change to its disinfection practice must calculate the disinfection benchmark, provide the benchmark to the State, and consult with the State for approval before making the significant change. The LT1ESWTR describes four types of significant changes to disinfection practices:

- Changes to the point of disinfection;

- Changes to the disinfectant(s) used in the treatment plant;

- Changes to the disinfection process; or,

- Any other modification identified by the State.

As part of the consultation and approval process, a system must submit the following information to the State:

- A description of the proposed change.

- The disinfection profile and disinfection benchmark for *Giardia*. If the system uses chloramines, ozone, or chlorine dioxide for primary disinfection, the system must also submit a profile and benchmark for viruses.

- An analysis of how the proposed change will affect the current levels of disinfection.

- Any additional information requested by the State.

Disinfection profiling and benchmarking will help ensure that microbial protection is not compromised by any modifications to disinfection practices. These modifications are discussed in more detail in Section 7.3.

Stage 1 DBPR = Stage 1 Disinfectants and Disinfection Byproducts Rule

7.3 SIMULTANEOUS COMPLIANCE

The LT1ESWTR is not the only rule that affects or dictates disinfection practices. The Stage 1 DBPR applies to some or all PWSs (depending on the disinfectant used) that add chlorine, chloramines, chlorine dioxide, or ozone. This rule establishes MCLs for TTHM and HAA5, in addition to other byproducts (depending on the disinfectant used). The MCLs are 0.080 mg/L for TTHM and 0.060 mg/L for HAA5 under
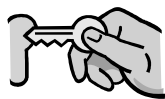
the Stage 1 DBPR. Surface water systems and systems classified as GWUDI that serve less than 10,000 people must comply with this rule by January 1, 2004. The Stage 1 DBPR also establishes maximum residual disinfectant levels (MRDLs) for systems using chlorine, chloramines, and chlorine dioxide.

The following terms may be helpful for understanding disinfection practices:

Disinfection Byproducts = DBP

- **Disinfection Byproduct (DBP) Precursors** – DBP precursors are constituents naturally occuring in source water that react with a disinfectant to form DBPs. The primary DBP precursor is natural organic matter, which is monitored as total organic carbon (TOC). Organic matter reacts with the disinfectant to form TTHM, HAA5, and other DBPs. The *Alternative Disinfectants and Oxidants Guidance Manual* (EPA, 1999a) provides more detailed information on DBP formation.

- **Pre-disinfection** – Pre-disinfection occurs when a disinfectant is added to the treatment train prior to the primary disinfectant injection location. The purpose of pre-disinfection is to obtain additional inactivation credits, to control microbiological growth in subsequent treatment processes, to improve coagulation, and/or to reduce tastes and odors.

- **Primary Disinfection** – The disinfectant used in a treatment system with the primary objective to achieve the necessary microbial inactivation.

- **Secondary Disinfection** – The disinfectant applied following primary disinfection in a treatment system with the primary objective to maintain the residual disinfectant throughout the distribution system.

7.3.1 Changes to the Point of Disinfection

Any change in the location of the disinfectant application constitutes a significant change to disinfection practices. For instance, a water system that uses pre-disinfection may consider moving the point of disinfectant application further into the treatment train (See Figure 7-1). This modification will result in a reduction of contact time between DBP precursors and the disinfectant(s) with corresponding reduction (typically) in the production of DBPs. Also, moving the pre-disinfection to a location after some of the treatment processes where organics have been removed will result in less contact between organic matter (precursors) and disinfectant; therefore, fewer DBPs should be created.

Example:
Moving the point of pre-disinfectant application

Figure 7-1. Example of Moving the Point of Pre-disinfectant Application

① Potential locations for pre-disinfection. For example, the system may consider relocating the pre-disinfection location from the intake to one of three other possible locations. The potential for DBP formations decreases further down the treatment train for two reasons:

1. Contact time between DBP precursors and disinfectants is reduced.

2. DBP precursors are removed with each subsequent treatment process.

A system that is considering moving the point of disinfectant application further into the treatment process should make sure that it can maintain adequate contact time and meet required log inactivations.

When moving the point of disinfection further into the treatment process, a system should consider whether adequate contact time will still be available to achieve sufficient disinfection. This type of modification may affect the amount of inactivation achieved by the system. Systems may find that seasonal use of this type of modification is helpful in reducing summertime DBP levels, which are typically the highest.

Systems should identify all impacts on the treatment process and maintain compliance with all rules when moving the point of disinfectant application.

In conventional treatment, DBP precursors are removed through coagulation, sedimentation, and filtration. Moving the point of disinfectant application to another point downstream from these processes can reduce the concentration of DBP precursors that come in contact with the disinfectant. However, moving the disinfectant application point downstream also reduces the time that the disinfectant is in contact with the water and the CT_{calc} for the disinfectant. Increasing the disinfectant concentration can help maintain a higher CT_{calc}, but greater disinfectant concentrations also lead to increased DBP formation. In addition, the disinfectant concentration may be limited (depending on the disinfectant used) by the MRDL for the disinfectant. Another alternative for maintaining CT is to add baffling to the clearwell or to storage tanks downstream in order to increase the disinfectant contact time. An increase in the contact time value may allow a lower disinfectant concentration and may result in fewer disinfection byproducts. However, the system must make sure it provides enough disinfectant to achieve the required microbial inactivation values.

7.3.2 Changes to the Disinfectant(s) Used in the Treatment Plant

Water systems typically use one or more of the following disinfectants:

- Chlorine;

- Chloramines;

- Chlorine Dioxide;

- Ozone; or,

- Ultraviolet (UV).

A water system may consider changing the disinfectant used in its treatment plant to comply with the Stage 1 DBPR MCLs.

Systems may also consider changing both the disinfectant and point of disinfection application. For example, a system may shift from chlorine as the sole source of disinfection to chlorine prior to the clearwell (primary disinfection) and ammonia added after the clearwell for chloramine (secondary disinfection) (See Figure 7-2). This configuration allows for chlorine to achieve *Giardia* and virus inactivation in the clearwell. The addition of ammonia after the clearwell to produce chloramines can reduce the formation of DBPs in the distribution system. In another example, a system may move the pre-disinfection location from a point prior to the presedimentation basin to a point prior to coagulation. In addition, the system may change the pre-disinfectant from chlorine to ozone to reduce TTHM and HAA5 formation (See Figure 7-3).

Considerations for alternative disinfectants.

As a system considers different disinfectants, it should evaluate the following:

- What DBPs are created by the disinfectant?

- What concentrations and contact times are required to provide adequate microbial inactivation?

- Where is the best point of application in the treatment train to minimize DBP's and maximize inactivations?

For more information on disinfectants, refer to Chapter 8 of this guidance manual and the *Alternative Disinfectants and Oxidants Guidance Manual* (EPA, 1999a), available on EPA's website http://www.epa.gov/safewater/mdbp/implement.html.

Example:
Changing disinfectant type

Figure 7-2. Example of Changing Disinfectant Type

Chlorine is used as the sole disinfectant and is added prior to the clearwell to obtain *Giardia* and virus inactivation.

The system decides to add ammonia after the clearwell to produce chloramine. Using chloramine as a secondary disinfectant has two advantages:

1) Chloramine typically has a lower potential for TTHM and HAA5 formation than chlorine. Chloramine should result in lower TTHM and HAA5 formation in the distribution system.

2) Chloramine residuals last longer than chlorine.

Example:
Changing pre-disinfection location and type of disinfectant

Figure 7-3. Changing Pre-disinfection Location and Type of Disinfectant

Change pre-disinfection location from prior to the pre-sedimentation basin (point 1) to prior to coagulation (point 2). Changing from chlorine to ozone may also be considered to reduce TTHM and HAA5 formation.
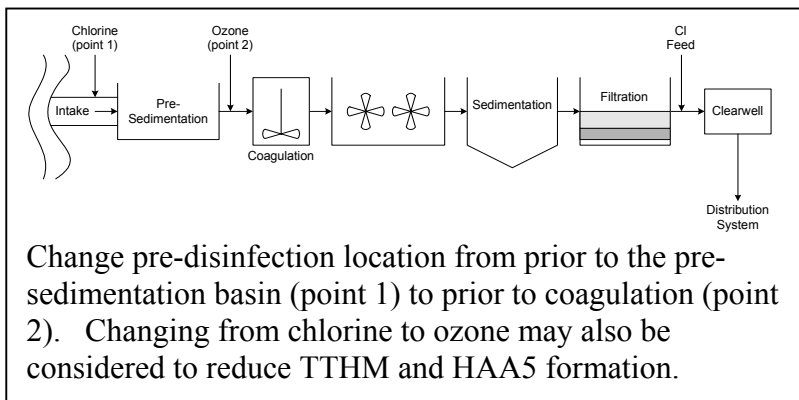
7.3.3 Changes to the Disinfection Process

Other changes to the disinfection process also require water systems to consult with the State before making the treatment change. Some modifications to the disinfection process include the following:

- Changing the contact basin geometry and baffling conditions to provide additional contact time;

- Increasing or decreasing the pH during disinfection; or,

- Decreasing the disinfectant dose during warmer temperatures.

The LT1ESWTR requires water systems to submit information to the State prior to making a change (See Section 7.2).

Effects of Basin Geometry and Baffling Conditions on Contact Time

Changing the contact basin geometry or baffling conditions may result in more inactivation by changing the T value in the CT_{calc} value. With this modification, additional inactivation is achieved without increasing the disinfectant concentration.

pH Effects on Chlorine

Chlorine is very sensitive to pH. Decreases in pH provide increased inactivation of *Giardia* and viruses. Therefore, at lower pHs a lower chlorine dose or contact time can be applied while achieving a sufficient level of inactivation of both *Giardia* and viruses. This in turn can reduce the potential for DBP formation. However, decreasing the pH is a process-sensitive issue and could result in other system changes, such as increased coagulant demand for proper floc formation, distribution system corrosion problems, or precipitation of certain inorganics. Extensive jar tests and pilot scale studies may be necessary before adjusting the pH.

Chlorine is pH sensitive and more effective at lower pHs.
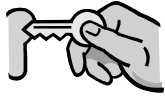
Chlorine is temperature sensitive and more effective at higher temperatures.

Temperature Effects on Chlorine and DBP Formation

Chlorine is more effective at higher temperatures, which results in faster chemical reactions and consequently, a higher potential for DBP formation. Warmer surface waters also support more organic growth, increasing the potential for DBP formation. However, since chlorine is more reactive at higher temperatures, it is also more effective against microorganisms such as *Giardia* and viruses. Thus, when water temperatures are warmer the chlorine dose or contact time can be decreased while achieving the same amount of microbial inactivation as in cooler temperatures. However, if a system decreases the chlorine dose or contact time, the system should ensure that it is maintaining sufficient log inactivations of both *Giardia* and viruses.

7.3.4 Other Modifications

The State may determine that other changes in water system operations should be considered significant changes in disinfection practices. If the State makes such a determination, systems that make these other significant changes must develop and submit a disinfection benchmark.

The modifications listed in Sections 7.3.1 through 7.3.3 are not an exhaustive list. States may determine that other types of changes are also significant. Therefore, a water system should check with the State program office for assistance in determining whether a proposed change triggers the disinfection benchmarking procedure. Other modifications that may require State consultation and approval are enhanced coagulation, enhanced softening, or oxidation. Water systems can refer to the *Alternative Disinfectants and Oxidants Guidance Manual* (EPA, 1999a) and the *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual* (EPA, 1999b) for additional information. Copies of these guidance manuals can be obtained by downloading from EPA's website at http://www.epa.gov/safewater/mdbp/implement.html.

The State may use the benchmark to make sure that modifications to disinfection practices still maintain required microbial inactivation.

7.4 HOW THE STATE WILL USE THE BENCHMARK

The State is expected to use the benchmark to evaluate the microbial inactivation the system has achieved over time and compare this with the expected microbial inactivation the system will achieve by disinfection practice modifications.

Systems with a benchmark that is less than the inactivation requirements in Table 7-2 or those required by the State will probably need to modify disinfection practices in order to provide the necessary level of disinfection. For instance, a conventional treatment plant has calculated a benchmark of 0.3 for *Giardia* but is required to achieve 0.5-log *Giardia* inactivation through disinfection. This system would need to provide additional disinfection to achieve the required 0.5-log *Giardia* inactivation. At the same time, systems must also make sure that they maintain compliance with the Stage 1 DBPR. The system must consult with the State for approval and provide all necessary information prior to any significant modification, as described in Section 7.2.

Systems may consider modifying disinfection practices if the benchmark is greater than the inactivation requirements in Table 7-2 or the inactivation required by the State. For instance, a conventional treatment plant has calculated a benchmark of 1.3 for *Giardia* but is only required to achieve a 0.5-log *Giardia* inactivation through disinfection. The system uses chlorine and is having difficulties complying with TTHM and HAA5 MCLs established by the Stage 1 DBPR. The system considers decreasing the amount of chlorine, but must determine what level of chlorine is needed to meet the 0.5-log *Giardia* inactivation and still maintain compliance with the Stage 1 DBPR. Again, the system must consult with the State for approval prior to making any significant modifications and must provide all necessary information.

The benchmark may be used by the State as a minimum level of inactivation of *Giardia* and viruses that must be maintained by water systems when modifying disinfection practices. The State may also use the disinfection profile and benchmark to determine an appropriate alternative benchmark under different disinfection scenarios. The *LT1ESWTR Implementation Guidance Manual* (under development at this time) will provide additional information on how States will use the disinfection profile and benchmark.

7.5   STEPS COMPLETED
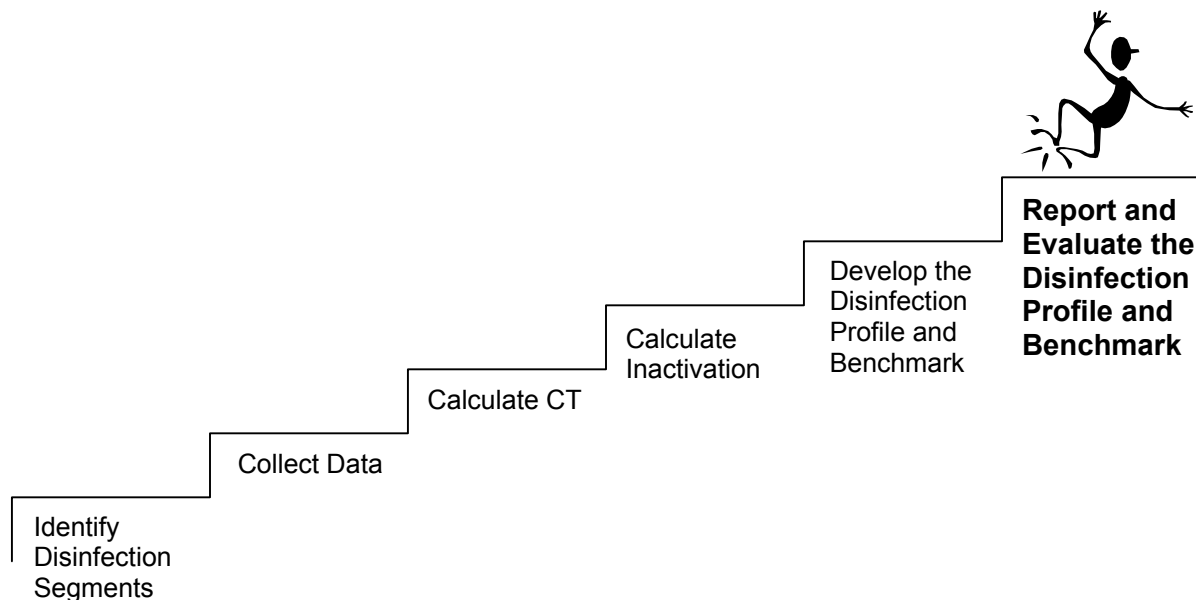
7.6   REFERENCES

EPA. 1999a. *Alternative Disinfectants and Oxidants Guidance Manual* (EPA 815-R-99-014). Washington, D.C.

EPA. 1999b. *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual* (EPA 815-R-99-012). Washington, D.C.

8. TREATMENT CONSIDERATIONS

For more information on alternative disinfectants and oxidants, see the *Alternative Disinfectants and Oxidants Guidance Manual* (EPA, 1999a), available on EPA's website http://www.epa.gov/safewater/mdbp/implement.html.

8.1 INTRODUCTION

In order to comply with the requirements of the LT1ESWTR and the Stage 1 DBPR, water systems may decide to make changes to their disinfection practices or other treatment processes. Disinfection profiling and benchmarking will help ensure that microbial protection is not compromised by any of these modifications. Since DBPs are formed when organic material reacts with disinfectants such as chlorine, water systems may choose to use less chlorine or modify treatment processes to reduce the formation of DBPs. Some methods that water systems may use to control disinfection byproducts, while meeting the required inactivation levels for *Giardia* and viruses, include the use of alternative disinfectants and oxidants, enhanced coagulation and softening, increasing the contact time, or the use of alternative filtration techniques, such as membranes. Pilot testing is generally recommended before any of these major modifications are made to plant processes. The State must also be consulted for approval prior to any modifications.

8.2 ALTERNATIVE DISINFECTANTS AND OXIDANTS

This section discusses various alternative disinfectants and oxidants that may be considered for meeting both inactivation and Stage 1 DBPR requirements. A more complete discussion of this topic is provided in the *Alternative Disinfectants and Oxidants Guidance Manual* (EPA, 1999a).

Chlorine has long been considered an effective disinfectant in water systems and is the most widely used disinfectant by small systems. Chlorine is typically used in one of three forms: chlorine gas, sodium hypochlorite (typically liquid), and calcium hypochlorite (typically solid). Chlorine effectively inactivates a wide range of pathogens, including *Giardia* and viruses. Chlorine residuals are generally carried into the distribution system for further protection. The Stage 1 DBPR established an MRDL of 4.0 mg/L measured as chlorine if chlorine is used (community and non-transient non-community water systems). Remember, surface water and GWUDI systems must maintain a residual disinfectant concentration of 0.2 mg/L at the entry point to the distribution system and must

maintain a detectable residual disinfectant in the distribution system (40 CFR Section 141.72).

The use of chlorine as a disinfectant, particularly as a pre-disinfectant, has typically been found to increase the formation of DBPs. One option to resolve this problem is to use a different pre-disinfectant or an oxidant such as chlorine dioxide, ozone, or potassium permanganate. The type of oxidant used and its concentration have significant effects on DBP formation. Consideration should also be given to the pH of the water, since lowering the pH decreases TTHM formation but increases formation of other chlorinated organic species (Dowbiggin and Thompson, 1990). In addition, higher temperatures speed up the reaction between chlorine and organic material, thus increasing finished water TTHM and HAA5 levels (Singer, 1999).

Retaining adequate disinfectant residual at all points in the water distribution system is important to inhibit bacteriological growth, and using chlorine to achieve this has been a widely accepted practice. However, the long detention time for water at the ends of water mains promotes DBP formation when chlorine is used. An alternative disinfectant, such as chloramines, may then be an option.

Alternative disinfectants and oxidants to consider are chloramines, ozone, chlorine dioxide, ultra-violet radiation, and potassium permanganate.

8.2.1 Chloramines (NH_2Cl)

Stage 1 DBPR
For community and non-transient non-community water systems using chloramines:

MRDL of 4.0 mg/L as chlorine.

Chloramines are formed when chlorine and ammonia are added together, either simultaneously or sequentially. The ammonia can be applied before or after the chlorine. However, applying ammonia after the chlorine has been found to inactivate pathogens more effectively (AWWA, 1999). Chloramination is normally practiced as a ratio of approximately 1 part of ammonia to 4 parts of chlorine (on a mg/L basis) to ensure monochloramine formation (Kawamura, 2000). Chloramines are typically used as a secondary disinfectant since they are more stable than chlorine and can provide better protection in the distribution system (Kawamura, 2000). To meet required inactivations of *Giardia* and viruses, chloramines require more contact time than chlorine. Chloramines typically have a lower potential than chlorine for producing DBPs. The Stage 1 DBPR established an MRDL of 4.0 mg/L as chlorine for systems using chloramines. The CT tables presented in Appendix B of this guidance document assume ammonia is added <u>after</u> chlorine to form chloramines.
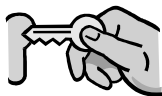
8.2.2 Ozone (O₃)

Stage 1 DBPR
For community and non-transient non-community water systems using ozone:

MCL for bromate
= 0.010 mg/L

Over the last fifteen years, the most widely studied alternative to chlorine as a disinfectant has been ozone (Schneider and Tobiason, 2000). Ozone is used for both oxidation and disinfection. It must be generated at the point of application, since it is an unstable molecule. Ozone is a powerful oxidant and is more effective than chlorine, chloramines, and chlorine dioxide for inactivation of viruses, *Cryptosporidium*, and *Giardia* (EPA, 1999a).

Ozone effectively oxidizes DBP precursors, but its effectiveness is pH and temperature dependent. It can only be used as a primary disinfectant, since it is unable to maintain a residual in the distribution system. Chlorine or chloramines should also be applied as a secondary disinfectant to maintain the residual.

The use of ozone poses some health and safety concerns that should be addressed by a utility considering its use. Instrumentation should be provided for ozone systems to protect both personnel and the equipment. Ozone is highly corrosive and toxic, and ozonation systems are relatively complex. While ozone does not form halogenated DBPs except in bromide-rich waters, it does form a variety of organic and inorganic byproducts, such as bromate. Bromate is regulated by the Stage 1 DBPR at 0.010 mg/L.

Case Study – Schneider and Tobiason (2000)
Jar-testing was used to study the effects of preozonation on interactions among coagulants, particles, and natural organic matter. Synthetic water (deionized, distilled water with organic matter, particles, and background ions added) and waters from Lake Gaillard in Branford, Connecticut; the Oradell reservoir in Oradell, New Jersey; and the Passaic River in Little Falls, New Jersey, were tested. Experiments were run with ozone only and with ozone followed by coagulation. The research found that when alum was used as a coagulant, preozonation hindered the removal of turbidity and dissolved organic matter (DOM) at the conditions tested. Cationic polymers, however, allowed small increases in the removal of turbidity and DOM. It was found that varying the preozone contact time from 4 to 28 minutes had little effect on settled water turbidity, TOC, and dissolved organic carbon for the conditions tested.

Case Study – Ashe, et al. (1994)

The Brewer Water District, serving 9,100 customers, operates pumping and treatment facilities in Eddington, Maine. The water system draws its water from Hatcase Pond, disinfects with sodium hypochlorite, adjusts the pH with caustic soda, adds sodium fluoride for fluoridation, and sends the treated water to a 50,000-gallon clearwell. In order to comply with new and pending regulations, the system needed to reduce TTHMs and achieve a 3-log inactivation of *Giardia* cysts and a 4-log inactivation of viruses. The District began addressing its disinfection concerns by studying its present water quality and disinfection practices. The raw water supply was found to exhibit a high chlorine demand and a rapid rate of TTHM formation. The use of ozone, chlorine dioxide, and chloramines were considered in place of chlorine disinfection. The use of chloramines was determined to be economically unfeasible due to the large volume of additional storage required in order to meet CT criteria. Pending legislation for the regulation of chlorine dioxide byproducts (chlorite is now regulated) eliminated it from further consideration. Ozone was therefore chosen as a primary disinfectant for pilot plant study. Results showed that ozonation at a dose of 2.0 mg/L to 3.5 mg/L and a contact time of 6 to 9 minutes would provide the required CT value for this system under all water temperatures and pH conditions, and adequately destroy the organic compounds that form DBPs. Chloramines were chosen for use as a secondary disinfectant in order to maintain a residual throughout the distribution system while reducing trihalomethane formation in the distribution system.
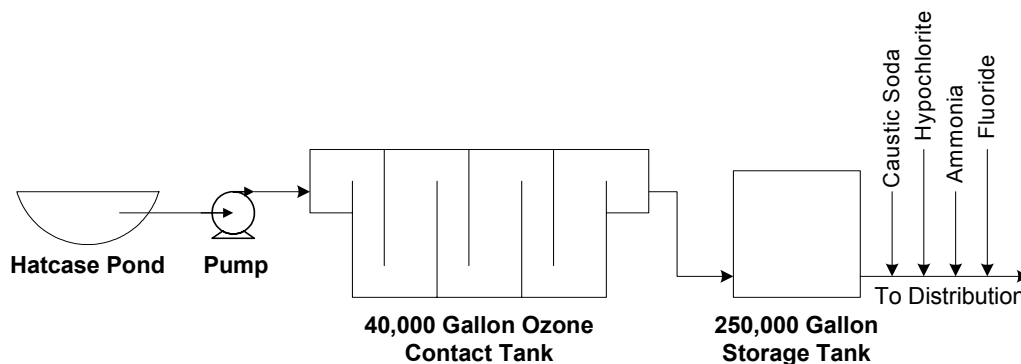
Brewer Water District proposed treatment process.

8.2.3 Chlorine Dioxide (ClO$_2$)

Chlorine dioxide is a powerful oxidant and disinfectant that is effective at inactivating bacterial, viral, and protozoan pathogens. Chlorine dioxide is generated on-site and is equal or superior to chlorine in its disinfection ability. Chlorine dioxide is primarily used in the United States as a means of taste and odor control, oxidation of iron and manganese, and control of TTHM and HAA5 (Kawamura, 2000). Chlorine dioxide doses are limited due to production of chlorite. The Stage 1 DBPR regulates chlorite. Utilities using chlorine dioxide may have to use granular activated carbon (GAC) or a chemical reducing agent, such as sulfur dioxide, to remove the chlorite residual.

Stage 1 DBPR
For water systems using chorine dioxide:

MRDL of 0.8 mg/L as ClO_2.

MCL of chlorite of 1.0 mg/L (only applies to community and non-transient non-community systems).

Chlorine dioxide is a strong oxidant and aids in reducing TTHM and HAA5 by oxidizing precursors. Chlorine dioxide can also be used to reduce taste and odors or as a primary or secondary disinfectant. Chlorine dioxide has the ability to maintain a residual in the distribution system for an extended period of time (Kawamura, 2000). The Stage 1 DBPR establishes an MRDL of 0.8 mg/L as ClO_2 for systems (community, non-transient non-community, and transient non-community) using chlorine dioxide.

8.2.4 Potassium Permanganate (KMnO$_4$)

Potassium permanganate is primarily used as a pre-oxidant to control algal growth, tastes, and odors, and to remove iron, manganese, and color. It may also be used to control DBP formation by oxidizing organic precursors and reducing the demand for other disinfectants (EPA, 1999a). **It is not allowed under the Surface Water Treatment Rule to be used as a disinfectant to achieve microbial inactivation.** A water treatment plant may choose to use potassium permanganate as a pre-oxidant, in lieu of chlorine, and then move the chlorination point further into the treatment train. This configuration may help in the control of DBPs by reducing the concentration of natural organic matter and delaying the introduction of chlorine until after the majority of precursors have been removed in the treatment process.

There are some disadvantages to using potassium permanganate. Potassium permanganate must be handled carefully when preparing the feed solution, since it can cause serious eye injury, irritate the skin and respiratory system, and can be fatal if swallowed. It also tends to turn the water a pink color.

EPA is currently developing a UV Guidance Manual.

8.2.5 Ultraviolet Radiation (UV)

UV light is becoming an increasingly popular method of disinfecting drinking water. One advantage of UV is that it does not cause the formation of harmful disinfection byproducts. Recent studies also show that UV can inactivate *Cryptosporidium* and *Giardia*. An additional advantage is that there are fewer safety concerns with using UV than with chemical disinfectants such as chlorine gas or chlorine dioxide. UV rays inactivate microorganisms by penetrating their cell

walls to damage essential cell components. UV is not effective on all pathogens, and studies are being done to identify UV's effectiveness.

The UV dose is the product of the irradiance and the time that an organism is exposed to that irradiance. The dose is expressed in millijoules per square centimeter (mJ/cm^2) or the equivalent, milliwatt-seconds per square centimeter ($mW·s/cm^2$). A common UV dose used in drinking water disinfection is 38-40 mJ/cm^2 (Cotton, et al., 2001). Data from recent research indicate that a dose of 40 mJ/cm^2 will achieve at least a 2-log inactivation of *Cryptosporidium* (Cotton, et al., 2001). *Giardia* is thought to be equally as sensitive as or more sensitive than *Cryptosporidium* to UV light. Bacteria are more susceptible to UV disinfection than *Cryptosporidium*. Some viruses are significantly less susceptible to UV disinfection than *Cryptosporidium* and bacteria. Thus, virus inactivation is likely to control the dose when UV is used as the only disinfectant in drinking water treatment.

Despite the many advantages of UV systems, these systems also have some shortcomings. Since UV is a physical disinfectant, not a chemical disinfectant, it does not leave a residual in the water. Thus, a secondary disinfectant must be applied to maintain distribution system residuals. Another disadvantage is that higher turbidity may shield organisms and prevent them from being exposed to UV. Additionally, organic material absorbs UV light and can increase the UV demand of the water. Therefore, it is recommended that systems apply UV light as a disinfectant after filtration, where turbidity and organics in the water are reduced. Another potential problem is that scale can form on the quartz sleeves that house the UV lamps, depending on the ions, hardness, alkalinity, and pH of the water. This in turn causes a reduction in the amount of UV energy that is transmitted to the water. However, regular cleaning of the sleeves can reduce the effects of scaling. Finally, the operation of the UV lamps may be temperature dependent.

8.2.6 Comparison of Disinfectants

Systems should conduct a pilot study prior to eliminating or adding a disinfectant.

EPA and the Association of Metropolitan Water Agencies (AMWA) funded a two-year study of 35 water treatment facilities to evaluate DBP production based on various combinations of primary and secondary disinfectants. Among four of the facilities, alternative disinfection strategies were

investigated to evaluate the difference in DBP production from the systems' previous disinfection strategies (or base disinfection conditions). The results were analyzed in three reports (Metropolitan and Montgomery, 1989; Jacangelo, et al., 1989; Malcolm Pirnie, Inc., 1992) that documented different aspects of the study. Table 8-1 summarizes the results of the study. This study illustrates that a change in primary disinfectant from chlorine to ozone or to chloramines may help reduce TTHM and HAA5.

Table 8-1. Study Results on Changing Primary and Secondary Disinfectants

Change in Disinfection Practice[1] (Primary Disinfectant/Secondary Disinfectant)		DBP Concentration Change	
		TTHM	**HAA5**
Chlorine/Chlorine To Chlorine/Chloramines[2]	Utility #7	Decrease	Decrease
Chlorine/Chlorine To Ozone/Chlorine	Utility #19	Decrease	Decrease
	Utility #36	No change	No change
Chlorine/Chloramines To Ozone/Chloramines	Utility #7	Decrease	Decrease
Chlorine/Chlorine To Chloramines/Chloramines	Utility #36	Decrease	Decrease
Ozone/Chlorine To Ozone/Chloramines	Utility #36	Decrease	Decrease
Chloramines/Chloramines To Ozone/Chloramines	Utility #25	Decrease	Decrease
	Utility #36	No change	No change
Chlorine/Chlorine To Ozone/Chloramines	Utility #7	Decrease	Decrease
	Utility #36	Decrease	Decrease

[1]Several studies were conducted to examine the effects of changing primary and secondary disinfectants on DBP levels. For instance, changing the secondary disinfectant from chlorine to chloramines resulted in a decrease in both TTHM and HAA5. Results are based on full-scale evaluations at Utilities #19 and #25 and on pilot scale evaluations at Utilities #7 and #36.

[2]Free chlorine contact time was 4 hours for Utility #7 during use of chlorine/chloramine strategy.

Source: Malcolm Pirnie, Inc., 1992; Jacangelo, et al., 1989.

8.3 CHANGES IN ENHANCED COAGULATION AND SOFTENING

Enhanced softening means the improved removal of DBP precursors by precipitative softening.

Enhanced coagulation means the addition of sufficient coagulant for improved removal of DBP precursors by conventional filtration treatment.

Guidance for implementing enhanced coagulation or enhanced precipitative softening is provided in the *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual* (EPA, 1999b).

In conventional water treatment plants, precursors of DBPs may be removed through the coagulation process with aluminum or ferric salts and/or polymers. If a greater reduction in the DBP level is required, then the treatment techniques of either enhanced coagulation or enhanced precipitative softening can be employed.

With fewer precursors present, the formation of DBPs is thereby reduced. Enhanced coagulation also allows for more effective disinfection, since the chlorine demand is lower in water treated by enhanced coagulation. In addition, the lower pH resulting from enhanced coagulation allows chlorine to inactivate *Giardia* more effectively, since chlorine is more effective at lower pHs.

One way to implement enhanced coagulation is to change the type or dose of coagulant and/or polymer aid. However, before either enhanced coagulation or enhanced softening is implemented at a water treatment plant, the proposed changes should be evaluated through pilot-testing or bench-scale studies. Jar testing is commonly used to simulate coagulant dose changes and its effectiveness. A water treatment plant should first determine the present status of the coagulation process by taking TOC samples from the raw water and the finished water. With this data, the percent removal of TOC may be calculated and a desired TOC removal level may be determined.

Changes to the coagulation and softening processes may have secondary effects on a water treatment plant. The pH of the water may be altered by the changes, thus affecting the disinfection process. Over the typical plant pH operating range of 5.5 to 9.5, decreasing the pH values improves the disinfection characteristics of chlorine and ozone and decreases the effectiveness of chlorine dioxide (EPA, 1999b). Another secondary effect of enhanced coagulation or softening may be the production of a lighter and more fragile floc that can carry over into the filters, thus shortening filter runs and increasing the amount of filter backwash water produced. Efficient sedimentation is extremely important prior to the filters to prevent filter overload. More sludge may also result from enhanced coagulation and enhanced softening, because of

increased coagulant and lime dosages and more TOC removal. In addition, inorganic contaminant levels for iron, manganese, aluminum, sulfate, chloride, and sodium in finished water may increase with increased coagulant dosages (depending on type of coagulant used). A recent study by Carlson, et al. (2000) presents secondary effects of enhanced coagulation and softening.

Case Study – Kramer and Horger (1998)

The Samuel S. Baxter Water Treatment Plant in Philadelphia conducted a series of jar tests to look at enhanced coagulation and its impact on TOC removal from the source water. At the time of the study, the 200 MGD Baxter plant used pre-treatment, flocculation/sedimentation, filtration, and disinfection to treat its water. It seasonally used potassium permanganate as a preoxidant to control algae and its associated tastes and odors. Ferric chloride was used as the primary coagulant. This enhanced coagulation study considered the pH of coagulation as well as the coagulant dose. Jar tests using treatment plant water showed that the optimal pH was significantly less than the pH that was being used in the plant for coagulation and that the coagulant dose could be reduced by 10-30%. Full scale testing at the water treatment plant showed that by reducing the pH of coagulation, TTHM formation was significantly reduced and TOC removal increased significantly. Further investigation is necessary to determine the impact of lower pH on the formation of haloacetic acids.

Case Study - Bell-Ajy, et al. (2000)

Research, including jar tests using raw water from 16 water utilities throughout the United States and two full-scale evaluations, was conducted to evaluate the optimal coagulation conditions for removal of TOC and DBPs. Jar test results showed that when optimized coagulation was implemented, treatment effectiveness seemed pH dependent. Jar tests using alum, ferric chloride, and polyaluminum chloride coagulants with sulfuric acid for pH reduction removed more TOC than those at higher pH levels. In the full-scale applications, enhanced coagulation effectively increased TOC removal and reduced trihalomethanes and trihalomethane formation potentials. With a lowering of pH during the coagulation process, turbidity and particle removals were improved. The researchers recommended that sludge generation, floc carryover, and dewatering, along with the point of chlorine addition and alkalinity consumption, be considered in the treatment scheme before enhanced coagulation is implemented.

8.4 INCREASING CONTACT TIME

Increasing either C (the disinfectant residual concentration) or T (the contact time for the disinfectant) will increase the CT value and provide additional credit for *Giardia* cyst and virus reductions. The value of CT can be increased by constructing additional storage, increasing the disinfectant residual, changing the disinfectant, lowering the pH, increasing the minimum clearwell depth, lowering high service peak flows, or improving clearwell hydraulics to allow for a greater detention time (Bishop, 1993). Increasing disinfectant concentrations to improve CT poses the problem of increasing the formation of DBPs, particularly with chlorine. One way to gain additional disinfection credit without increasing the disinfectant dosage is to increase the detention time in the clearwell. Increased detention time serves to allow more contact time, thus providing more opportunity for the destruction of microorganisms.

Another way to increase CT is to construct additional storage prior to high service pumping. However, the cost and utilization of available space makes this option less preferred (Bishop, 1993). These suggested operating scenarios may limit DBP formations if the majority of DBP precursors have been removed. If a significant amount of DBP precursors, such as organic matter, is present when the disinfectant is added, these scenarios may not be advantageous.

As discussed in Chapter 4 of this manual, the detention time used in the CT calculation is not the theoretical detention time (basin volume divided by flow rate), but rather the amount of time in which 10 percent of the fluid passes through a basin, process, or system in which a disinfectant residual is maintained. This value is determined from tracer tests or is estimated with the use of a baffling factor. Certain basin shapes and designs allow good mixing, while others allow short-circuiting. The baffling factors listed in Table 4-2 account for various baffling conditions, inlet/outlet designs, and basin configurations. A water system desiring more contact time in order to increase its CT value may improve the hydraulics of its existing clearwell by improving the detention time within the unit through baffling or inlet/outlet changes.

Possible clearwell changes are:

- Relocating the inlet and/or outlet to maximize the separation distance between them;

- Perforating the distribution and collection piping to disperse flow across the clearwell;

- Using overflow inlets to disperse existing horizontal inlet flows;

- Using baffles to disperse inlet flow;

- Perforating baffle walls to disperse flows into and out of basins; and,

- Using inlet or outlet weirs or launderers to distribute flow (Bishop, 1993).

Case Study – Pinsky, et al. (1991)

The South Central Connecticut Regional Water Authority (RWA) hired a consulting firm to conduct a comprehensive study of current disinfection practices at three of its surface water treatment plants. Two of these plants (Lake Gaillard and West River) are direct filtration plants and the third one (Lake Saltonstall) is a conventional water treatment plant. Where current disinfection practices were found to be inadequate, disinfection strategies and alternatives for satisfying CT requirements were investigated and recommendations were developed. Tracer studies confirmed that the filtered water reservoirs experienced short-circuiting. After research of various physical and chemical alternatives, the recommendation for the West River plant was the construction of a single vertical baffle in the finished water reservoirs at a total cost of $147,000. At the Lake Gaillard Plant, it was determined that a single vertical baffle in each of the two finished water reservoirs, at a total project cost of $120,000, would meet the CT requirement.

Case Study – Teefy, et al. (1995)

The Alameda County Water District (ACWD) in Fremont, California, was not meeting the disinfection requirements of the SWTR or its DBP requirements. The existing water treatment plant was a conventional surface water treatment plant that used free chlorine for disinfection, alum and cationic polymer for coagulation and filtration, and chloramines for secondary disinfection. In order to receive additional disinfection credit, it was decided that the plant's 750,000-gallon reservoir should be modified to obtain more detention time for the chlorine. The common inlet/outlet configuration of the tank did not allow for any contact time credit. In order to determine the best type and location of the new inlet and outlet structures, more than 50 configurations were tested in a scale modeling study. Twenty minutes was determined to be the desired T_{10} after the improvements were completed. Based on the model results, a spiral-type arrangement with the inlet coming in tangential to the side of the tank and the outlet line coming directly out of the bottom center of the tank was chosen. In addition to these changes to the reservoir, the point of sodium hydroxide and aqua ammonia addition was moved from immediately after the filters to downstream of the newly-modified reservoir. This move was made to slow the formation of trihalomethanes and to make the required CT requirement easier to achieve. The total project cost of $1,800,000 included the modeling study, engineering design, and actual construction of the improvements. The full-scale results were close to the model predictions, but agreement was not always good. Tests at the mid-range operating depth agreed best with the model predictions.
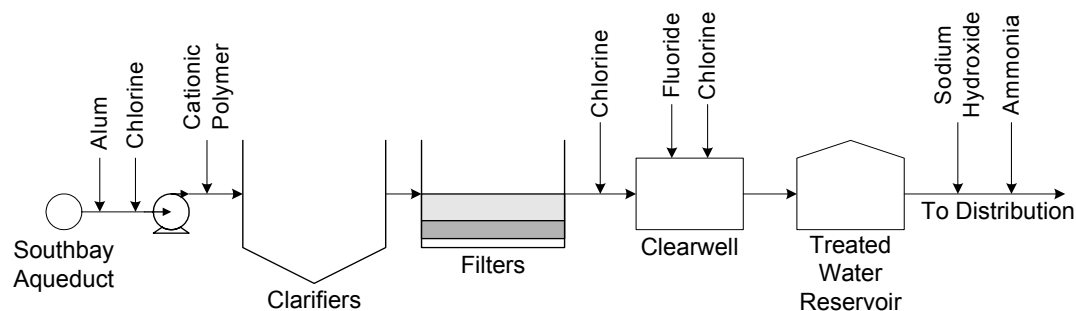
8.5 MEMBRANES

Four basic classes of membrane technology are currently used in the water treatment industry: reverse osmosis, nanofiltration, ultrafiltration, and microfiltration. Figure 8-1 presents the typical pore size range and removal capabilities for these membrane process classes. Membranes have a distribution of pore sizes, and this distribution will vary according to the membrane material and manufacturing process. When a pore size is stated, it can be presented as either nominal (i.e., the average pore size) or absolute (i.e., the maximum pore size) in terms of microns (μm). The removal capabilities of reverse osmosis and nanofiltration membranes are typically not stated in terms of pore size, but instead as a molecular weight cutoff representing the approximate size of the smallest molecule that can be removed by the membrane.

All of these membrane processes are effective at removing *Giardia, Cryptosporidium*, and most bacteria (provided the membrane has no leaks). The amount of removal will depend on the type of membrane used. Reverse osmosis, nanofiltration, and ultrafiltration should remove viruses, assuming there are no leaks in the membranes. Reverse osmosis and nanofiltration are capable of removing inorganic and organic contaminants, including DBP precursors (AWWA, 1999).

Membranes can be effective in decreasing the amount of DBPs formed:

- The removal of pathogens by membranes should reduce the amount of disinfectant required for inactivation and should result in lower finished water DBP concentrations; and,

- The removal of DBP precursors should result in lower finished water DBP concentrations (when reverse osmosis or nanofiltration is used).

It is important to remember that these membrane processes are physical barriers only, and must be followed by disinfection to ensure inactivation of pathogens not removed by the membrane barrier, control of bacterial regrowth in downstream system plumbing, and an adequate distribution system residual. Membranes can also be used to achieve other treatment

For more information on membranes, refer to *Membrane Practices for Water Treatment* (AWWA, 2001).

objectives. More information on membranes can be obtained from the *Guidance Manual for Membrane Filtration* (under development by EPA-OGWDW).

Case Study – Bing, et al. (2001)

The Delta Water Treatment Plant in Delta, Ohio, which serves approximately 3,200 people, treats river water with lime-soda softening and filtration. In order to meet increasing demand and upcoming regulations the plant needed to upgrade the facility. An integrated membrane system, consisting of microfiltration and reverse osmosis, was chosen for a pilot study. The microfiltration filtrate was blended with the reverse osmosis permeate to reduce the demand on the reverse osmosis system while still meeting water quality objectives. The dissolved organic carbon, trihalomethane formation potential, and haloacetic acid formation potential were substantially reduced by reverse osmosis and in the blended water were well within the compliance levels of the Stage 1 DBPR. Turbidity, hardness, and particulate removal goals of 0.05 NTU, 110-150 mg/L, and 2 logs, respectively, were also surpassed in the blended water. An additional benefit of this system was that the pH of the finished water was lower than in the existing system, meaning that a lower chlorine dose could be used to meet CT requirements, further reducing the formation of DBPs. This study showed that this integrated membrane system is suitable for small systems using surface water sources.

Figure 8-1. Particles Removed Through Membrane Technologies

	Ionic Range	Molecular Range		Macro Molecular Range	Micro Particle Range	Macro Particle Range	
Micron Scale	0.001	0.01	0.1	1.0	10	100	1000
Approximate Molecular Weight	100	1000 10,000	100,000	500,000			

Typical Size Range of Selected Water Constituents: Dissolved Organics · Giardia · Sand · Bacteria · Viruses · Salts · Colloids · Cryptosporidium

Membrane Process*: Particle Filtration · Microfiltration · Ultrafiltration · Nanofiltration · Reverse Osmosis

* Particle Filtration is shown for reference only. It is not a membrane separation process.

Source: AWWA/ASCE, 1998.

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Appendix A
Glossary

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A.1 GLOSSARY

baffle. A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solutions, slurry).

baffling factor (BF). The ratio of the actual contact time to the theoretical detention time.

clarifier. A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom by gravity. Clarifiers are also called settling basins and sedimentation basins.

clearwell. A reservoir for the storage of filtered water with sufficient capacity to prevent the need to vary the filtration rate in response to short-term changes in customer demand. Also used to provide chlorine contact time for disinfection.

coagulant. A chemical added to water that has suspended and colloidal solids to destabilize particles, allowing subsequent floc formation and removal by sedimentation, filtration, or both.

coagulation. As defined in 40 CFR 141.2, a process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

community water system (CWS). A public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

conventional filtration treatment. As defined in 40 CFR 141.2, a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

Cryptosporidium. A disease-causing protozoan widely found in surface water sources. *Cryptosporidium* is spread by the fecal-oral route as a dormant oocyst from human and animal feces. In its dormant stage, *Cryptosporidium* is housed in a very small, hard-shelled oocyst form that is resistant to chlorine and chloramine disinfectants. When water containing these oocysts is ingested, the protozoan may cause a severe gastrointestinal disease called <u>cryptosporidiosis</u>.

CT or CT$_{calc}$. As defined in 40 CFR 141.2, the product of "residual disinfectant concentration" (C) in mg/l determined before or at the first customer, and the corresponding "disinfectant contact time" (T) in minutes, i.e., "C" x "T". If a public water system applies disinfectants at more than one point prior to the first customer, it must determine the CT of each disinfectant sequence before or at the first customer to determine the total percent inactivation or "total inactivation ratio". In determining the total inactivation ratio, the public water system must determine the residual disinfectant concentration of each disinfection sequence and corresponding contact time before any subsequent disinfection application point(s). "CT$_{99.9}$" is the CT value required for 99.9 percent (3-log) inactivation of *Giardia lamblia* cysts. CT$_{99.9}$ for a variety of disinfectants and conditions appear in Tables 1.l- 1.6, 2.1, and 3.1 of §141.74(b)(3) in the Code of Federal Regulations. CT$_{calc}$/CT$_{99.9}$ is the inactivation ratio. The sum of the inactivation ratios, or total inactivation ratio shown as Σ [(CT$_{calc}$) / (CT$_{99.9}$)] is calculated by adding together the inactivation ratio

for each disinfection sequence. A total inactivation ratio equal to or greater than 1.0 is assumed to provide a 3-log inactivation of *Giardia lamblia* cysts.

detention time. The average length of time a drop of water or a suspended particle remains in a tank or chamber. Mathematically, it may be determined by dividing the volume of water in the tank by the flow rate through the tank.

diatomaceous earth filtration. As defined in 40 CFR 141.2, a process resulting in substantial particulate removal, that uses a process in which: (1) a "precoat" cake of diatomaceous earth filter media is deposited on a support membrane (septum), and (2) while the water is filtered by passing through the cake on the septum, additional filter media, known as "body feed," is continuously added to the feed water to maintain the permeability of the filter cake.

direct filtration. As defined in 40 CFR 141.2, a series of processes including coagulation and filtration, but excluding sedimentation, and resulting in substantial particulate removal.

disinfectant. As defined in 40 CFR 141.2, any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines, and ozone added to water in any part of the treatment or distribution process, that is intended to kill or inactivate pathogenic microorganisms.

disinfectant contact time. As defined in 40 CFR 141.2, the time in minutes that it takes for water to move from the point of disinfectant application or the previous point of disinfectant residual measurement to a point before or at the point where residual disinfectant concentration ("C") is measured. Where only one "C" is measured, "T" is the time in minutes that it takes for water to move from the point of disinfectant application to a point before or at where residual disinfectant concentration ("C") is measured. Where more than one "C" is measured, "T" is (a) for the first measurement of "C", the time in minutes that it takes for water to move from the first or only point of disinfectant application to a point before or at the point where the first "C" is measured and (b) for subsequent measurements of "C", the time in minutes that it takes for water to move from the previous "C" measurement point to the "C" measurement point for which the particular "T" is being calculated. Disinfectant contact time in pipelines must be calculated based on "plug flow" by dividing the internal volume of the pipe by the maximum hourly flow rate through that pipe. Disinfectant contact time within mixing basins and storage reservoirs must be determined by tracer studies or an equivalent demonstration.

disinfection. As defined in 40 CFR 141.2, a process which inactivates pathogenic organisms in water by chemical oxidants or equivalent agents.

disinfection benchmark. The lowest monthly average microbial inactivation during the disinfection profile time period.

disinfection byproduct precursors. Substances that can be converted into disinfection byproducts during disinfection. Typically, most of these precursors are constituents of natural organic matter. In addition, the bromide ion (Br^-) is a precursor material.

disinfection byproducts (DBPs). Inorganic and organic compounds formed by the reaction of the disinfectant, natural organic matter, and the bromide ion during water disinfection processes. Regulated DBPs include trihalomethanes, haloacetic acids, bromate, and chlorite.

disinfection profile. As stated in 40 CFR 141.530, a graphical representation of your system's level of *Giardia lamblia* or virus inactivation measured during the course of a year.

disinfection segment. A section of the system beginning at one disinfectant injection or monitoring point and ending at the next disinfectant injection or monitoring point.

effluent. Water or some other liquid that is raw, partially or completely treated that is flowing from a reservoir, basin, treatment process or treatment plant.

enhanced coagulation. As defined in 40 CFR 141.2, the addition of sufficient coagulant for improved removal of disinfection byproduct precursors by conventional filtration treatment.

enhanced softening. As defined in 40 CFR 141.2, the improved removal of disinfection byproduct precursors by precipitative softening.

filtration. As defined in 40 CFR 141.2, a process for removing particulate matter from water by passage through porous media.

finished water. Water that has passed through a water treatment plant such that all the treatment processes are completed or "finished" and ready to be delivered to consumers. Also called product water.

flocculation. As defined in 40 CFR 141.2, a process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

Giardia lamblia. Flagellated protozoan, which is shed during its cyst-stage with the feces of man and animals. When water containing these cysts is ingested, the protozoan causes a severe gastrointestinal disease called giardiasis.

ground water under the direct influence of surface water (GWUDI). As defined in 40 CFR 141.2, any water beneath the surface of the ground with significant occurrence of insects or other macroorganisms, algae, or large-diameter pathogens such as *Giardia lamblia* or *Cryptosporidium*, or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation.

haloacetic acids five (HAA5). As defined in 40 CFR 141.2, the sum of the concentrations in milligrams per liter of the haloacetic acid compounds (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid), rounded to two significant figures after addition.

influent water. Raw water plus recycle streams.

interpolation. A technique used to determine values that fall between the marked intervals on a scale.

log inactivation. The percentage of microorganisms inactivated through disinfection by a given process.

log reduction. The percentage of microorganisms reduced through log removal added to the log inactivation. One log reduction means that 90% of the microorganisms are removed or inactivated. Two log corresponds to 99%, three log is 99.9% and four log corresponds to 99.99%.

log removal. The percentage of microorganisms physically removed by a given process.

maximum contaminant level (MCL). As defined in 40 CFR 141.2, the maximum permissible level of a contaminant in water which is delivered to any user of a public water system.

membrane filtration. A filtration process (e.g., reverse osmosis, nanofiltration, ultrafiltration, and microfiltration) using tubular or spiral-wound elements that exhibits the ability to mechanically separate water from other ions and solids by creating a pressure differential and flow across a membrane.

micrograms per liter (μg/L). One microgram of a substance dissolved in each liter of water. This unit is equal to parts per billion (ppb) since one liter of water is equal in weight to one billion micrograms.

micron. A unit of length equal to one micrometer (μm). One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

milligrams per liter (mg/L). A measure of concentration of a dissolved substance. A concentration of one mg/L means that one milligram of a substance is dissolved in each liter of water. For practical purposes, this unit is equal to parts per million (ppm) since one liter of water is equal in weight to one million milligrams. Thus a liter of water containing 10 milligrams of calcium has 10 parts of calcium per one million parts of water, or 10 parts per million (10 ppm).

non-community water system (NCWS). As defined in 40 CFR 141.2, a public water system that is not a community water system. A non-community water system is either a "transient non-community water system (TWS)" or a non-transient non-community water system (NTNCWS)."

non-transient non-community water system (NTNCWS). As defined in 40 CFR 141.2, a public water system that is not a community water system and that regularly serves at least 25 of the same persons over six months per year.

organics. Carbon-containing compounds that are derived from living organisms.

oxidant. Any oxidizing agent; a substance that readily oxidizes (removes electrons from) something chemically. Common drinking water oxidants are chlorine, chlorine dioxide, ozone, and potassium permanganate. Some oxidants also act as disinfectants.

oxidation. A process in which a molecule, atom, or ion loses electrons to an oxidant. The oxidized substance (which lost the electrons) increases in positive valence. Oxidation never occurs alone, but always as part of an oxidation-reduction (redox) reaction.

pathogens, or pathogenic organisms. Microorganisms that can cause disease (such as typhoid, cholera, or dysentery) in other organisms or in humans, animals and plants. They may be bacteria, viruses, or protozoans and are found in sewage, in runoff from animal

farms or rural areas populated with domestic and/or wild animals, and in water used for swimming. There are many types of microorganisms which do not cause disease. These microorganisms are called non-pathogens.

pH. pH is an expression of the intensity of the basic or acid condition of a solution. Mathematically, pH is the negative logarithm (base 10) of the hydrogen ion concentration, [H+]. [pH = log (1/H+)]. The pH may range from 0 to 14, where 0 is most acidic, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

plug flow. The water travels through a basin, pipe, or unit process in such a fashion that the entire mass or volume is discharged at exactly the theoretical detention time of the unit.

pre-disinfection. The addition of a disinfectant to the treatment train prior to the primary disinfectant injection location. Generally, the purpose of pre-disinfection is to obtain additional inactivation credits, to control microbiological growth in subsequent treatment processes, to improve coagulation, or to reduce tastes and odors.

primary disinfection. The disinfectant used in a treatment system to achieve the necessary microbial inactivation.

public water system (PWS). As defined in 40 CFR 141.2, a system for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes: any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. Such term does not include any "special irrigation district." A public water system is either a "community water system" or a "non-community water system".

reservoir. Any natural or artificial holding area used to store, regulate, or control water.

secondary disinfection. The disinfectant application in a treatment system to maintain the disinfection residual throughout the distribution system.

sedimentation. As defined in 40 CFR 141.2, a process for removal of solids before filtration by gravity or separation.

short-circuiting. A hydraulic condition in a basin or unit process that occurs when the actual flow time of water through the basin is less than the basin or unit process volume divided by the peak hourly flow.

State. As defined in 40 CFR 141.2, the agency of the State or Tribal government which has jurisdiction over public water systems. During any period when a State or Tribal government does not have primary enforcement responsibility pursuant to Section 1413 of the Safe Drinking Water Act, the term "State" means the Regional Administrator, U.S. Environmental Protection Agency.

surface water. As defined in 40 CFR 141.2, all water which is open to the atmosphere and subject to surface runoff.

total organic carbon (TOC). As defined in 40 CFR 141.2, total organic carbon in mg/L measured using heat, oxygen, ultraviolet irradiation, chemical oxidants, or combinations of these oxidants that convert organic carbon to carbon dioxide, rounded to two significant figures.

total trihalomethanes (TTHM). As defined in 40 CFR 141.2, the sum of the concentration in milligrams per liter of the trihalomethane compounds (trichloromethane [chloroform], dibromochloromethane, bromodichloromethane and tribromomethane [bromoform]), rounded to two significant figures.

trihalomethane (THM). As defined in 40 CFR 141.2, one of the family of organic compounds, named as derivatives of methane, wherein three of the four hydrogen atoms in methane are each substituted by a halogen atom in the molecular structure.

tracer. A foreign substance mixed with or attached to a given substance for subsequent determination of the location or distribution of the foreign substance.

tracer study. A study using a substance that can readily be identified in water (such as a dye) to determine the distribution and rate of flow in a basin, pipe, ground water, or stream channel.

transient non-community water system. As defined in 40 CFR 141.2, means a non-community water system that does not regularly serve at least 25 of the same persons over six months per year.

virus. As defined in 40 CFR 141.2, a virus of fecal origin which is infectious to humans by waterborne transmission.

water supply system. The collection, treatment, storage, and distribution of potable water from source to consumer.

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Appendix B
CT Tables

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TABLE B-1
CT VALUES* FOR 3-LOG INACTIVATION
OF *GIARDIA* CYSTS BY FREE CHLORINE

Chlorine Concentration (mg/L)	Temperature <=0.5°C pH							Temperature =5°C pH							Temperature = 10°C pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	137	163	195	237	277	329	390	97	117	139	166	198	236	279	73	88	104	125	149	177	209
0.6	141	168	200	239	286	342	407	100	120	143	171	204	244	291	75	90	107	128	153	183	218
0.8	145	172	205	246	295	354	422	103	122	146	175	210	252	301	78	92	110	131	158	189	226
1.0	148	176	210	253	304	365	437	105	125	149	179	216	260	312	79	94	112	134	162	195	234
1.2	152	180	215	259	313	376	451	107	127	152	183	221	267	320	80	95	114	137	166	200	240
1.4	155	184	221	266	321	387	464	109	130	155	187	227	274	329	82	98	116	140	170	206	247
1.6	157	189	226	273	329	397	477	111	132	158	192	232	281	337	83	99	119	144	174	211	253
1.8	162	193	231	279	338	407	489	114	135	162	196	238	287	345	86	101	122	147	179	215	259
2.0	165	197	236	286	346	417	500	116	138	165	200	243	294	353	87	104	124	150	182	221	265
2.2	169	201	242	297	353	426	511	118	140	169	204	248	300	361	89	105	127	153	186	225	271
2.4	172	205	247	298	361	435	522	120	143	172	209	253	306	368	90	107	129	157	190	230	276
2.6	175	209	252	304	368	444	533	122	146	175	213	258	312	375	92	110	131	160	194	234	281
2.8	178	213	257	310	375	452	543	124	148	178	217	263	318	382	93	111	134	163	197	239	287
3.0	181	217	261	316	382	460	552	126	151	182	221	268	324	389	95	113	137	166	201	243	292

Chlorine Concentration (mg/L)	Temperature = 15°C pH							Temperature = 20°C pH							Temperature = 25°C pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	49	59	70	83	99	118	140	36	44	52	62	74	89	105	24	29	35	42	50	59	70
0.6	50	60	72	86	102	122	146	38	45	54	64	77	92	109	25	30	36	43	51	61	73
0.8	52	61	73	88	105	126	151	39	46	55	66	79	95	113	26	31	37	44	53	63	75
1.0	53	63	75	90	108	130	156	39	47	56	67	81	98	117	26	31	37	45	54	65	78
1.2	54	64	76	92	111	134	160	40	48	57	69	83	100	120	27	32	38	46	55	67	80
1.4	55	65	78	94	114	137	165	41	49	58	70	85	103	123	27	33	39	47	57	69	82
1.6	56	66	79	96	116	141	169	42	50	59	72	87	105	126	28	33	40	48	58	70	84
1.8	57	68	81	98	119	144	173	43	51	61	74	89	108	129	29	34	41	49	60	72	86
2.0	58	69	83	100	122	147	177	44	52	62	75	91	110	132	29	35	41	50	61	74	88
2.2	59	70	85	102	124	150	181	44	53	63	77	93	113	135	30	35	42	51	62	75	90
2.4	60	72	86	105	127	153	184	45	54	65	78	95	115	138	30	36	43	52	63	77	92
2.6	61	73	88	107	129	156	188	46	55	66	80	97	117	141	31	37	44	53	65	78	94
2.8	62	74	89	109	132	159	191	47	56	67	81	99	119	143	31	37	45	54	66	80	96
3.0	63	76	91	111	134	162	195	47	57	68	83	101	122	146	32	38	46	55	67	81	97

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-2

CT VALUES* FOR
4- LOG INACTIVATION OF VIRUSES BY FREE CHLORINE

	pH	
<u>Temperature (^oC)</u>	<u>6-9</u>	<u>10</u>
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-3

**CT VALUES* FOR
3-LOG INACTIVATION OF *GIARDIA* CYSTS
BY CHLORINE DIOXIDE**

		Temperature (^{o}C)			
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
63	26	23	19	15	11

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-4

**CT VALUES* FOR
4-LOG INACTIVATION OF VIRUSES
<u>BY CHLORINE DIOXIDE pH 6-9</u>**

Temperature (^{o}C)

<u><= 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
50.1	33.4	25.1	16.7	12.5	8.4

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-5

**CT VALUES* FOR
3-LOG INACTIVATION OF *GIARDIA* CYSTS
<u>BY OZONE</u>**

Temperature (°C)					
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
2.9	1.90	1.43	0.95	0.72	0.48

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-6

CT VALUES* FOR
4-LOG INACTIVATION OF VIRUSES BY OZONE

Temperature (^{o}C)					
<u><= 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
1.8	1.2	1.0	0.6	0.5	0.3

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-7

CT VALUES* FOR
3-LOG INACTIVATION OF *GIARDIA* CYSTS
BY CHLORAMINE pH 6-9

Temperature (^{o}C)					
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
3,800	2,200	1,850	1,500	1,100	750

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-8

CT VALUES* FOR
4-LOG INACTIVATION OF VIRUSES BY CHLORAMINE

Temperature (°C)					
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
2,883	1,988	1,491	994	746	497

*Although units did not appear in the original tables, units are min-mg/L.

TABLE B-9

**CT VALUE* FOR
INACTIVATION OF VIRUSES BY UV**

Log Inactivation	
2.0	3.0
21	36

*Although units did not appear in the original tables, units are min-mg/L.

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Appendix C
Blank Worksheets

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The following worksheets can be used to record and report information to the State on *Giardia* or virus inactivation. Systems should check with their State prior to using these worksheets for acceptability.

A completed example of the Log Inactivation Ratio Determination worksheet (Worksheet#1) can be found in Chapters 3 through 5 and Appendix D of this Guidance Manual.

A completed example of the Total Log Inactivation Determination worksheet (Worksheet #2) can be found in Chapter 5 and Appendix D of this Guidance Manual.

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WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER[1]

Starting Month: _____ Year: _____   PWSID: _____ System/Water Source: _____

Disinfectant Type: _____   Prepared by: _____
Profile Type (check one): _____ *Giardia*   _____Viruses

Disinfection Segment/Sequence of Application[2]: _____

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (°C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT$_{Calc}$ = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1												
2												
3												
4												
5												
6												
7												
8												
9												
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*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

Notes:

1. The system is only required to calculate log inactivation values once per week on the same day of the week. For instance, the system may choose to calculate log inactivation values on Wednesday of every week. If the system has more than one point of disinfectant application or uses more than one type of disinfectant, then the system can calculate log inactivation ratios on separate sheets and sum the log inactivation ratios to obtain the total inactivation achieved by the plant using Worksheet #2 in Appendix C of the LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual.

2. Use a separate form for each disinfectant application point and related residual sample site. Enter the disinfectant and sequence position, e.g., "ozone/1st" or "chlorine dioxide/3rd".

3. Disinfectant concentration must be measured during peak hourly flow.

4. If the system uses chlorine, the pH of the disinfected water must be measured at the same location and time the chlorine residual disinfectant concentration is measured during peak hourly flow.

5. The water temperature must be measured at the same location and time the residual disinfectant concentration is measured during peak hourly flow. Temperature must be in degrees Celsius (^{o}C).

6. Peak hourly flow for the day must be provided for the disinfection segment.

7. The volume is the operating volume in gallons realized by the pipe, basin, or treatment unit process during peak hourly flow.

8. Theoretical detention time in minutes equals the volume in gallons in column 7 divided by the peak hourly flow in gpm in column 6.

9. Enter the baffling factor for the system's pipe, basin(s), or treatment unit process as determined by a tracer study or assigned by the State.

10. Disinfectant contact time in minutes is determined by multiplying the theoretical detention time in minutes in column 8 by the baffling factor in column 9.

11. CT_{calc} is determined by multiplying the residual disinfectant concentration in mg/L in column 3 by the disinfectant contact time in minutes in column 10.

12. The $CT_{required}$ value should be determined based on the tables contained in Appendix B of the LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual or tables in the Surface Water Treatment Rule Guidance Manual. $CT_{required}$ for *Giardia* is $CT_{99.9}$ (or 3-log inactivation) and $CT_{required}$ for viruses is $CT_{99.99}$ (or 4-log inactivation).

13. Inactivation ratio equals CT_{calc} in column 11 divided by $CT_{required}$ in column 12.

14. Log Inactivation for *Giardia* = 3 x Inactivation ratio in column 13.
    Log Inactivation for viruses = 4 x Inactivation ratio in column 13.

    For multiple disinfection segments, Worksheet #2 should be used to sum inactivation ratios for each disinfection segment to calculate system log inactivation.

WORKSHEET #2
TOTAL LOG INACTIVATION DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: _____ Year:_____   PWSID: _____

System/Water Source: _____   Prepared by: _____

Disinfectant Type: _____
Profile Type (check one): _____*Giardia*   _____Viruses

| Week # | Inactivation Ratio for each disinfection segment from Worksheet #1 | | | | | Sum of Inactivation Ratios | Total Log Inactivation[1] |
	Disinfection Segment 1	Disinfection Segment 2	Disinfection Segment 3	Disinfection Segment 4	Disinfection Segment 5		
1							
2							
3							
4							
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[1] *Giardia*: Log Inactivation = 3 x Sum of Inactivation Ratios
   Viruses: Log Inactivation = 4 x Sum of Inactivation Ratios (or a method approved by the State)

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Appendix D
Examples
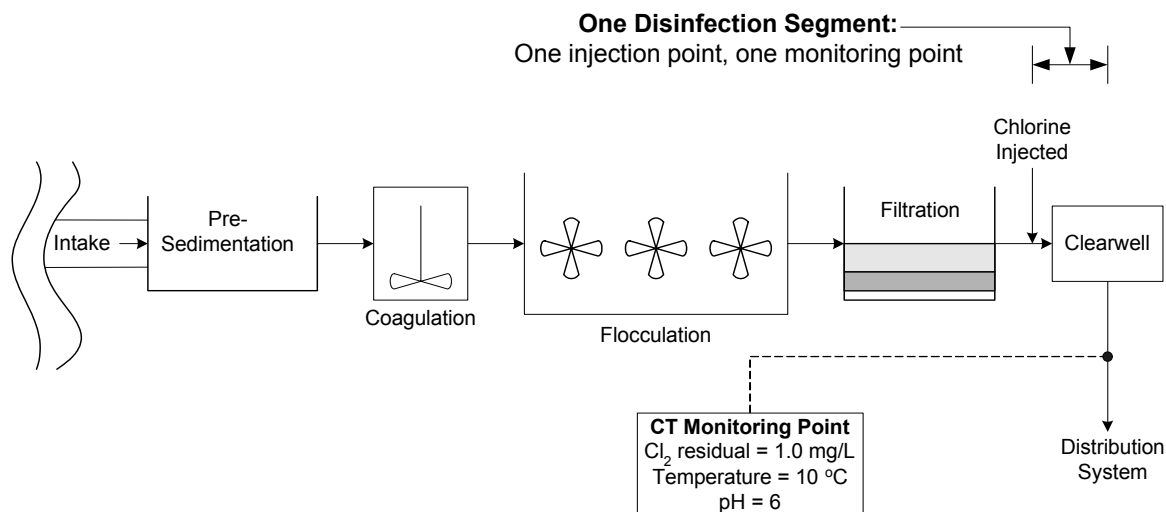
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This appendix provides example of ways a system may comply with the regulations for a disinfection profile and a disinfection benchmark. This appendix does not establish any additional requirements for completing a disinfection profile or a disinfection benchmark beyond the regulations established in the LT1ESWTR.

The following examples are presented in this appendix:

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Example D-1: Calculate Actual Log Inactivation for One Disinfectant

One Disinfection Segment:
One injection point, one monitoring point

CT Monitoring Point
Cl$_2$ residual = 1.0 mg/L
Temperature = 10 °C
pH = 6

In this example, the direct filtration treatment system added chlorine prior to the clearwell and it was required to create a disinfection profile. The system must determine the log inactivation for *Giardia* achieved through disinfection.

Step 1. Determine the peak hourly flow.

From the raw water pump records the peak hourly flow (Q) is determined to be 5,000 gallons per minute (gpm).

Step 2. Measure the chlorine residual, temperature, and pH (since chlorine is used) during peak hourly flow at the monitoring point and at the same time.

Temperature = 10ºC
pH = 6
Chlorine residual = **C$_{chlorine}$** = 1.0 mg/L

Step 3. Measure the physical dimensions of the clearwell.

Minimum Operating Depth
15.3 ft
75 ft
35 ft
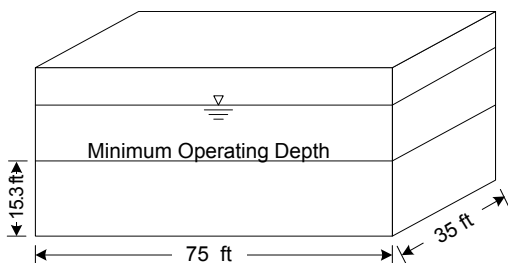
Example D-1 continued

Measure the inner tank length and width to obtain the volume of water in the clearwell rather than the volume of the tank itself.

Length = 75 ft
Width = 35 ft

Measure the minimum operating depth in the clearwell to obtain a conservative estimate of the volume of water in the tank.

Minimum Operating Depth = 15.3 ft

Step 4. Calculate the volume of the water in the clearwell based on low water level.

Volume (V) = minimum water depth x length x width
$\quad$ V = 15.3 ft x 75 ft x 35 ft = 40,160 ft^3
$\quad$ V = 40,160 ft^3 x (7.48 gal / ft^3)
$\quad$ **V = 300,000 gal**

Step 5. Calculate the Theoretical Detention Time (TDT) in the clearwell.

$\quad$ TDT = V / Q
$\quad$ TDT = 300,000 gal / 5,000 gpm
$\quad$ **TDT = 60 minutes**

Step 6. Determine the baffling factor (BF) for the clearwell.

Clearwell BF = 0.5 (from Table G-1 in Appendix G for average baffling condition as shown below.)
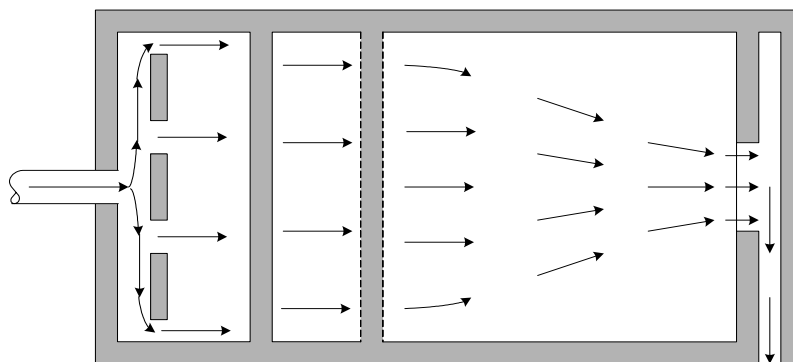
Step 7. Calculate the contact time of the disinfectant in the clearwell.

Contact Time (T) = TDT x BF
$\quad$ T = 60 min x 0.5
$\quad$ **T = 30 minutes**

Example D-1 continued

Step 8. Calculate the CT for the disinfection segment.

$$CT_{calc} = C_{chlorine} \text{ x } T$$
$$CT_{calc} = 1.0 \text{ mg/L x 30 min}$$
$$\textbf{CT}_{\textbf{calc}} = \textbf{30 min-mg/L}$$

Step 9. Determine the required CT$_{99.9}$ necessary to obtain 3-log Giardia inactivation.

The required CT value for 3-log *Giardia* inactivation (CT$_{99.9}$) may be obtained by using CT Table B-1 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine. In this example, the required CT$_{99.9}$ is 79 min-mg/L for a pH of 6, temperature of 10 ^{o}C, and C$_{chlorine}$ of 1.0 mg/L. The relevant section of Table B-1 is reprinted below and the pertinent section of the table is highlighted.

Excerpt from Table B-1:
CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine
(10 ^{o}C portion of table, for concentrations from 0.4 to 1.2)

Chlorine Concentration (mg/L)	Temperature = 10 ^{o}C						
				pH			
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	73	88	104	125	149	177	209
0.6	75	90	107	128	153	183	218
0.8	78	92	110	131	158	189	226
1.0	79	94	112	134	162	195	234
1.2	80	95	114	137	166	200	240

Step 10. Calculate the inactivation ratio for the clearwell.

$$\text{Inactivation ratio } = CT_{calc} / CT_{99.9}$$
$$= (30 \text{ min-mg/L}) / (79 \text{ min-mg/L})$$
$$\textbf{Inactivation ratio} = 0.380$$

Step 11. Calculate the actual Giardia log inactivation for the clearwell.

$$\text{Log inactivation} = 3 \text{ x } CT_{calc} / CT_{99.9}$$
$$\text{Log inactivation} = 3 \text{ x } 0.380$$
$$\textbf{Log inactivation} = \textbf{1.14}$$

The *Giardia* log inactivation for this system is 1.14.

Example D-1 continued

Assuming the system received a 2.0 log *Giardia* removal credit from the State for direct filtration, it must achieve at least 1.0 log *Giardia* inactivation for a total 3.0 log *Giardia* reduction as required in the Surface Water Treatment Rule (40 CFR Section 141.70(a)(1)). The value of 1.14 log *Giardia* inactivation exceeds the required 1.0 log *Giardia* inactivation. A calculation for virus inactivation does not need to be performed since only free chlorine is used as a disinfectant.

The worksheets in Appendix C can be used to record data and calculate log inactivation. The table below demonstrates how to record the data from this example using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: _January_   Year:_2004_   PWSID: _AA6543210_   System/Water Source: _LMN Water Plant_

Disinfectant Type: _Free Chlorine_   Prepared by: Jim Operator
Profile Type (check one):   _X_ *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: Clearwell/1st

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (^{o}C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT$_{Calc}$ = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	1.0	6	10	5,000	300,000	60	0.5	30	30.0	79	0.38	1.14
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

Example D-2: Calculate Actual Log Inactivation for Three Disinfection Segments and Two Disinfectants
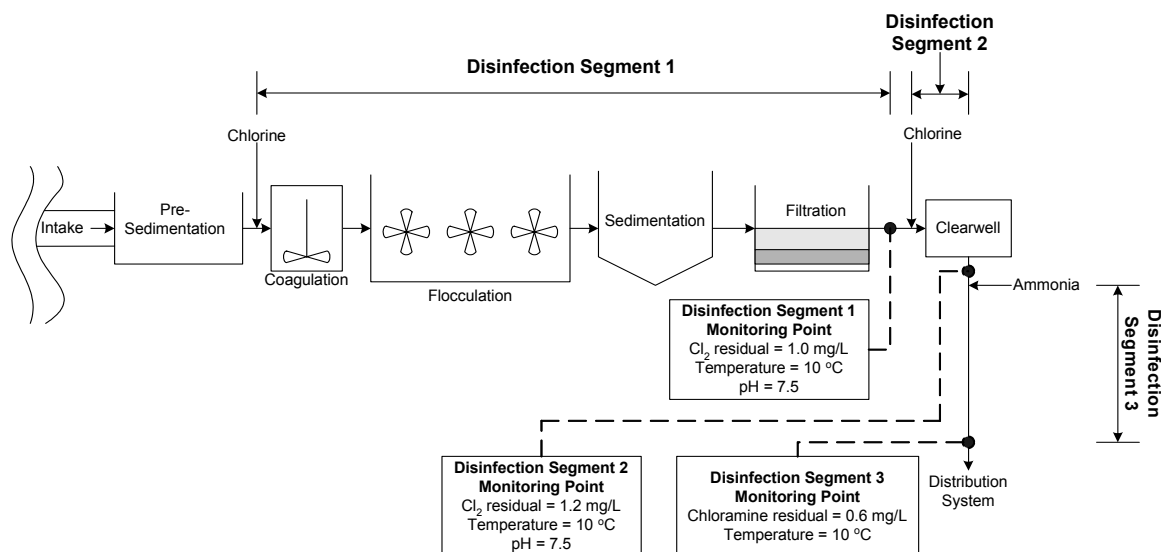
In this example chlorine is added to the conventional treatment system before coagulation as a predisinfectant and again prior to the clearwell as a primary disinfectant. Ammonia is added to the system after the clearwell to create chloramines as the secondary disinfectant to maintain a residual throughout the distribution system. The system was required to create a disinfection profile. Therefore, the system must determine the actual log inactivation for *Giardia* (Note: In this example virus log inactivations do not need to be calculated because chloramine is being used as a secondary disinfectant).

Since there are three points where the disinfectant is added, the inactivation ratio must be calculated for each disinfection segment.

A. Determine the *Giardia* Inactivation Ratio for Disinfection Segment 1

Disinfection Segment 1 begins at the chlorine injection location just prior to coagulation and ends at the chlorine monitoring point just after the filters.

Step 1. Determine the peak hourly flow.

From the raw water pump records the peak hourly flow (Q) is determined to be 5,000 gpm.

Step 2. Measure the chlorine residual, temperature, and pH (since chlorine is used) during peak hourly flow at the chlorine monitoring point and at the same time.

Temperature = 10°C
pH = 7.5
**Chlorine residual** = $C_{chlorine}$ = 1.0 mg/L

Example D-2 continued

Step 3. Measure the physical dimensions of the sub-units in Disinfection Segment 1.

Measure inner tank diameter or length and width to obtain the volume of water in the tanks rather than the volume of the tanks themselves.
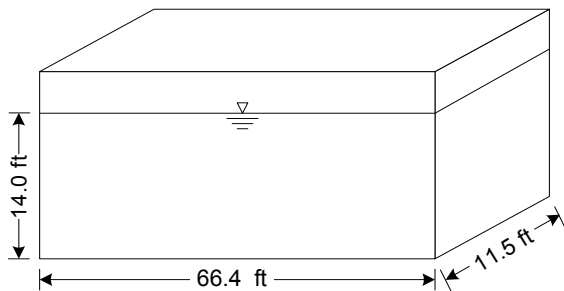
Measure the minimum operating depth in the tanks, where applicable, to obtain conservative estimates of the volume of water in the tanks.
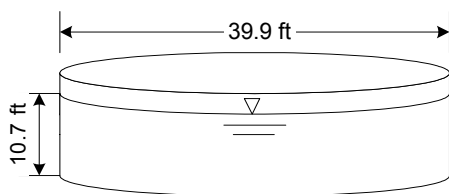
Coagulation:
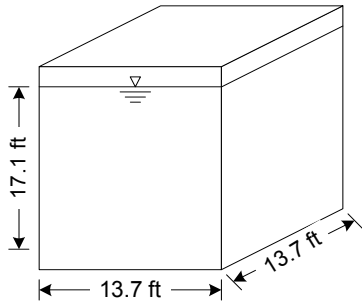
Length = 13.7 ft
Width = 13.7 ft
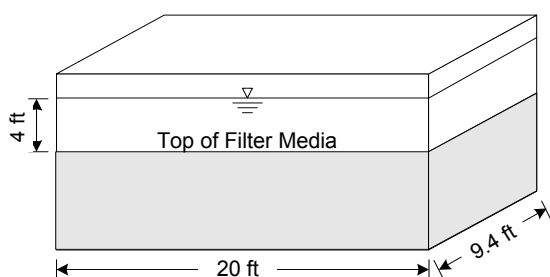Depth = 17.1 ft

Flocculation:

Length = 66.4 ft
Width = 11.5 ft
Depth = 14.0 ft

Example D-2 continued

Sedimentation:

       Diameter = 39.9 ft
       Depth = 10.7 ft

Filtration:

       Depth above filter media = 4 ft
       Length = 20 ft
       Width = 9.4 ft
       Number of filters = 8

Step 4. Calculate the volume of the water in each sub-unit in Disinfection Segment 1.

Coagulation:

Volume (V) = Length x Width x Depth
         V = 13.7 ft x 13.7 ft x 17.1 ft = 3,210 ft^3
         V = 3,210 ft^3 x (7.48 gal / ft^3)
         V = 24,000 gallons

Flocculation:

Volume (V) = Length x Width x Depth
         V = 66.4 ft x 11.5 ft x 14.0 ft = 10,690 ft^3
         V = 10,690 ft^3 x (7.48 gal / ft^3)
         V = 80,000 gallons

Example D-2 continued

Sedimentation:

Volume (V) = π x Radius^2 x Depth
           π = 3.14 (constant)
        Radius = Diameter / 2 = 39.9 / 2 = 19.95 ft
      V = 3.14 x (19.95 ft)^2 x 10.7 ft = 13,370 ft^3
      V = 13,370 ft^3 x (7.48 gal / ft^3)
      V = 100,000 gallons

Filtration:

Volume (V) = Length x Width x Depth of Water Above Media x # of Filters
      V = 20 ft x 9.4 ft x 4 ft x 8 filters = 6,020 ft^3
      V = 6,020 ft^3 x (7.48 gal / ft^3)
      V = 45,000 gallons

Step 5. Calculate the Theoretical Detention Time (TDT) in the sub-units in Disinfection Segment 1.

    TDT = V / Q

Coagulation:

    TDT = 24,000 gal / 5,000 gpm
    TDT = 4.8 minutes

Flocculation:

    TDT = 80,000 gal / 5,000 gpm
    TDT = 16 minutes

Sedimentation:

    TDT = 100,000 gal / 5,000 gpm
    TDT = 20 minutes

Filtration:

    TDT = 45,000 gal / 5,000 gpm
    TDT = 9 minutes

Example D-2 continued

Step 6. Determine the baffling factors (BF) for the sub-units in Disinfection Segment 1.

The table below summarizes the baffling factors in this example for the sub-units in Disinfection Segment 1.

Unit Process	BF *
(1) Coagulation	0.1
(2) Flocculation	0.1
(3) Sedimentation	0.5
(4) Filtration	0.7

*See Appendix G for Baffling Factors

Step 7. Calculate the contact time (T) in the sub-units in Disinfection Segment 1.

T = TDT x BF

Coagulation:

T = 4.8 min x 0.1
T = 0.48 minutes

Flocculation:

T = 16 min x 0.1
T = 1.6 minutes

Sedimentation:

T = 20 min x 0.5
T = 10 minutes

Filtration:

T = 9 min x 0.7
T = 6.3 minutes

Step 8. Calculate the total contact time in Disinfection Segment 1.

Total Contact Time (T_{total}) = Sum of T in each sub-unit
   T_{total} = 0.48 min + 1.6 min + 10 min + 6.3 min
   T_{total} = 18.4 minutes

Example D-2 continued

Step 9. Calculate the CT for Disinfection Segment 1 (CT_{calc})

CT_{calc} = $C_{chlorine}$ x T_{total}
CT_{calc} = 1.0 mg/L x 18.4 min
CT_{calc} = 18.4 min-mg/L

The CT_{calc} for Disinfection Segment 1 = 18.4 min-mg/L

Step 10. Determine the required $CT_{99.9}$ necessary to obtain 3-log Giardia *inactivation.*

The required CT value for 3-log *Giardia* inactivation ($CT_{99.9}$) may be obtained by using CT Table B-1 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine. The $CT_{99.9}$ in this example is 134 min-mg/L for a pH of 7.5, temperature of 10 ^{o}C, and $C_{chlorine}$ of 1.0 mg/L. The relevant section of Table B-1 is reprinted below and the pertinent section of the table is highlighted.

Excerpt from Table B-1:
CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine
(10 ^{o}C portion of table, for concentrations from 0.6 to 1.4)

Chlorine Concentration (mg/L)	Temperature = 10 ^{o}C						
				pH			
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
0.6	75	90	107	128	153	183	218
0.8	78	92	110	131	158	189	226
1.0	79	94	112	134	162	195	234
1.2	80	95	114	137	166	200	240
1.4	82	98	116	140	170	206	247

Step 11. Calculate the inactivation ratio for Disinfection Segment 1.

Inactivation ratio = CT_{calc} / $CT_{99.9}$
Inactivation ratio = (18.4 min-mg/L) / (134 min-mg/L)
Inactivation ratio = 0.137

Example D-2 continued

B. Determine the *Giardia* Inactivation Ratio for Disinfection Segment 2

Disinfection Segment 2 in this example begins at the chlorine injection location just prior to the clearwell and ends just after the clearwell.

Step 1. Determine the peak hourly flow.

The peak hourly flow (Q) for Disinfection Segment 2 is the same as the peak hourly flow in Disinfection Segment 1.

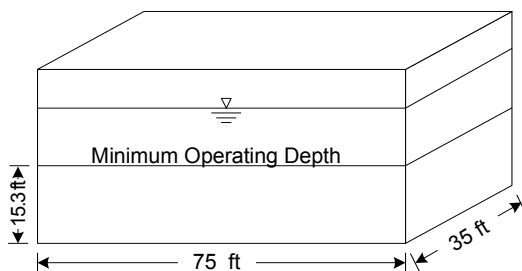**Peak hourly flow = 5,000 gpm.**

Step 2. Measure the chlorine residual, temperature, and pH (since chlorine is used) during peak hourly flow at the chlorine monitoring point and at the same time.

Temperature = 10°C
Chlorine residual = $C_{chlorine}$ = 1.2 mg/L
pH = **7.5**

Step 3. Measure the physical dimensions of the clearwell.

Measure the inner tank length and width to obtain the volume of water in the clearwell rather than the volume of the tank itself.

Length = 75 ft
Width = 35 ft

Measure the minimum operating depth in the clearwell to obtain a conservative estimate of the volume of water in the tank.

Minimum Operating Depth = 15.3 ft

Example D-2 continued

Step 4. Calculate the volume of the water in the clearwell based on low water level.

Volume (V) = minimum water depth x length x width
    V = 15.3 ft x 75 ft x 35 ft = 40,160 ft^3
    V = 40,160 ft^3 x (7.48 gal / ft^3)
    V = 300,000 gal

Step 5. Calculate the Theoretical Detention Time in the clearwell.

Theoretical Detention Time (TDT) = V / Q
  TDT = 300,000 gal / 5,000 gpm
  TDT = 60 minutes

Step 6. Determine the baffling factor for the clearwell.

Clearwell Baffling Factor (BF) = 0.7 (from Table G-1 for superior baffling condition as shown below.)
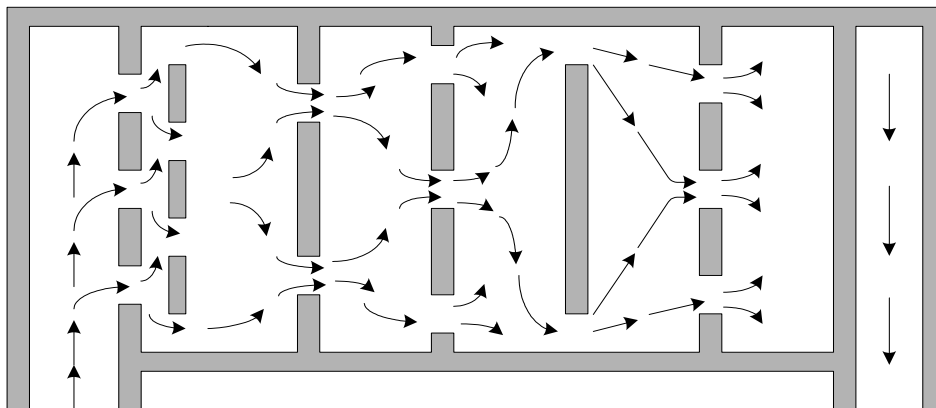
Step 7. Calculate the contact time of the disinfectant in the clearwell.

Contact Time (T) = TDT x BF
    T = 60 min x 0.7
    T = 42 minutes

Step 8. Calculate the CT for the disinfection segment.

CT_{calc} = $C_{chlorine}$ x T
CT_{calc} = 1.2 mg/L x 42 min
CT_{calc} = 50 min-mg/L

Example D-2 continued

Step 9. Determine the required CT$_{99.9}$ necessary to obtain 3-log **Giardia** *inactivation.*

The required CT value for 3-log *Giardia* inactivation (CT$_{99.9}$) may be obtained by using CT Table B-1 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine. The CT$_{99.9}$ in this example is 137 min-mg/L for a pH of 7.5, temperature of 10 ^{o}C, and C$_{chlorine}$ of 1.2 mg/L. The relevant section of Table B-1 is reprinted below and the pertinent section of the table is highlighted.

Excerpt from Table B-1:
CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine
(10 ^{o}C portion of table, for concentrations from 0.8 to 1.6)

Chlorine Concentration (mg/L)	Temperature = 10 ^{o}C						
				pH			
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
0.8	78	92	110	131	158	189	226
1.0	79	94	112	134	162	195	234
1.2	80	95	114	137	166	200	240
1.4	82	98	116	140	170	206	247
1.6	83	99	119	144	174	211	253

Step 10. Calculate the inactivation ratio for the clearwell.

Inactivation ratio = CT$_{calc}$ / CT$_{99.9}$
Inactivation ratio = (50 min-mg/L) / (137 min-mg/L)
Inactivation ratio = 0.365

C. Determine the *Giardia* Inactivation Ratio for Disinfection Segment 3

Disinfection Segment 3 in this example begins at the chloramine injection location after the clearwell and ends at the monitoring point in the transmission pipe, which is prior to the first customer.

Step 1. Determine the peak hourly flow.

The peak hourly flow (Q) for Disinfection Segment 3 is the same as the peak hourly flow in Disinfection Segment 1.
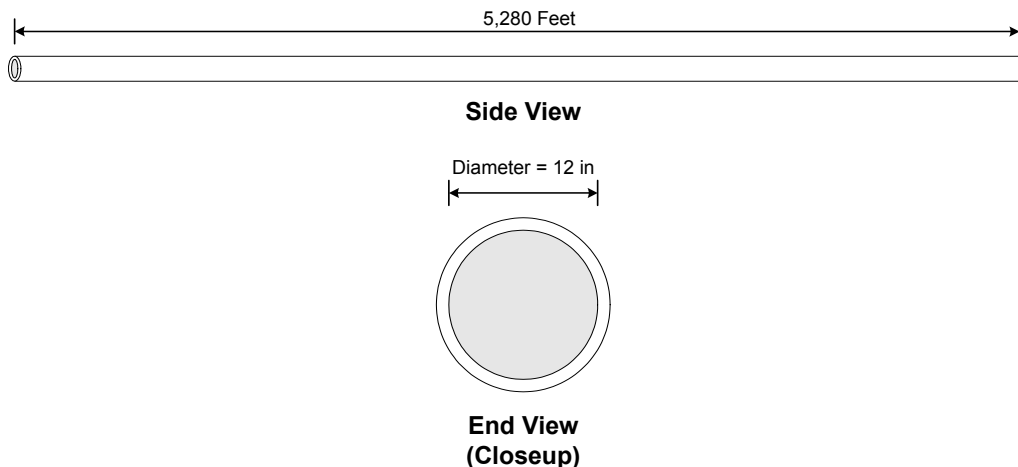
Peak hourly flow = 5,000 gpm.

Example D-2 continued

Step 2. Measure the chloramine residual and temperature during peak hourly flow at the chlorine monitoring point and at the same time.

Temperature = 10ºC
Chloramine residual = $C_{chloramine}$ = 0.6 mg/L

Step 3. Measure the physical dimensions of the pipe.

5,280 Feet

Side View

Diameter = 12 in

**End View
(Closeup)**

Measure the length of the pipe and the inner pipe diameter to obtain the volume of water in the pipe rather than the volume of the pipe itself.

Diameter = 12 in x (1 ft / 12 in) = 1 ft
Length = 5,280 ft

Step 4. Calculate the volume of the water in the pipe.

Volume (V) = π x Radius^2 x Length
π = 3.14 (constant)
Radius = Diameter / 2 = 1.0 / 2 = 0.5 ft
V = 3.14 x (0.5 ft)^2 x 5,280 ft = 4,140 ft^3
V = 4,140 ft^3 x (7.48 gal / ft^3)
V = 31,000 gallons

Step 5. Calculate the Theoretical Detention Time in the pipe.

Theoretical Detention Time (TDT) = V / Q
TDT = 31,000 gal / 5,000 gpm
TDT = 6.2 minutes

Example D-2 continued

Step 6. Determine the baffling factor for the pipe.

    Baffling Factor (BF) = 1.0 (from Table G-1 in Appendix G for a pipe)

Step 7. Calculate the contact time of the disinfectant in the pipe.

    Contact Time (T) = TDT x BF
        T = 6.2 min x 1.0
        T = 6.2 minutes

Step 8. Calculate the CT for the disinfection segment.

    $CT_{calc} = C_{chloramine}$ x T
    CT_{calc} = 0.6 mg/L x 6.2 min
    CT_{calc} = 3.7 min-mg/L

Step 9. Determine the required $CT_{99.9}$ necessary to obtain 3-log **Giardia** *inactivation.*

The required CT value for 3-log *Giardia* inactivation ($CT_{99.9}$) may be obtained by using CT Table B-7 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Chloramine pH 6-9. The $CT_{99.9}$ in this example is 1,850 min-mg/L for a temperature of 10 °C. Table B-7 is reprinted below and the pertinent section of the table is highlighted.

Table B-7:
CT Values for 3-Log Inactivation of *Giardia* Cysts by Chloramine pH 6-9

		Temperature (°C)			
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
3,800	2,200	1,850	1,500	1,100	750

Step 10. Calculate the inactivation ratio for the pipe.

    Inactivation ratio = CT_{calc} / $CT_{99.9}$
    Inactivation ratio = (3.7 min-mg/L) / (1,850 min-mg/L)
    Inactivation ratio = 0.002

Example D-2 continued

D. Determine Total *Giardia* Log Inactivation for the System.

Step 1. Determine the total Giardia *inactivation ratio for the system.*

Total Inactivation ratio $= \Sigma \ (CT_{calc} \ / \ CT_{99.9}) = 0.137 + 0.365 + 0.002 = 0.504$

Step 2. Determine the total Giardia *log inactivation for the system.*

Total log inactivation $= 3 \ x \ \Sigma \ (CT_{calc} \ / \ CT_{99.9})$
Total log inactivation $= 3 \ x \ (0.504)$
Total log inactivation $= 1.51$

The total *Giardia* log inactivation for the system is 1.51.

Assuming the system received a 2.5 log *Giardia* removal credit from the State for conventional filtration, it must achieve at least 0.5 log *Giardia* inactivation for a total 3.0 log *Giardia* reduction as required in the Surface Water Treatment Rule (40 CFR Section 141.70(a)(1)). The value of 1.51 log *Giardia* inactivation exceeds the required 0.5 log *Giardia* inactivation. A calculation for virus inactivation does not need to be performed since only free chlorine is used as the primary disinfectant.

E. Worksheets

The worksheets in Appendix C can be used to record data and calculate log inactivation.

The table below summarizes the calculations for each unit process in Disinfection Segment 1.

Unit Process	Volume (gal)	Peak Hourly Flow (gpm)	BF[*]	Contact Time (min)
Coagulation	24,000	5,000	0.1	0.48
Flocculation	80,000	5,000	0.1	1.6
Sedimentation	100,000	5,000	0.5	10
Filtration	45,000	5,000	0.7	6.3
Total:	**249,000**			**18.4**

* See Appendix G for baffling factors.

Example D-2 continued

The worksheet excerpt below demonstrates how data may be recorded from Disinfection Segment 1 using Worksheet #1 in Appendix C. For this example, Worksheet #1 needs to be copied so the data from each disinfection segment can be entered.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year:<u>2004</u>   PWSID:<u>AA7654321</u>   System/Water Source: <u>ABC Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: Jon Operator
Profile Type (check one): <u>X</u> *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: <u>Coagulation, Flocculation, Sedimentation, Filtration/1st</u>

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (^{o}C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT_{Calc} = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	1.0	7.5	10	5,000	249,000	**	**	18.4	18.4	134	0.137	
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.
**See the previous table showing details of each unit process for theoretical detention times and baffling factors.

The worksheet excerpt below demonstrates how data may be recorded from Disinfection Segment 2 using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: <u>January</u>   Year:<u>2004</u>   PWSID:<u>AA7654321</u>   System/Water Source: <u>ABC Water Plant</u>

Disinfectant Type: <u>Free Chlorine</u>   Prepared by: Jon Operator
Profile Type (check one): <u>X</u> *Giardia*   ____Viruses

Disinfection Segment/Sequence of Application: <u>Clearwell/2nd</u>

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (^{o}C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 CT_{Calc} = (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	1.2	7.5	10	5,000	300,000	60	0.7	42	50	137	0.365	
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

Example D-2 continued

The worksheet excerpt below demonstrates how data may be recorded from Disinfection Segment 3 using Worksheet #1 in Appendix C.

WORKSHEET #1
LOG INACTIVATION RATIO DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: _January_ Year: _2004_ PWSID: _AA7654321_ System/Water Source: _ABC Water Plant_

Disinfectant Type: _Chloramine_ Prepared by: _Jon Operator_
Profile Type (check one): _X_ *Giardia* ____ Viruses

Disinfection Segment/Sequence of Application: _Transmission Pipe/3rd_

Week #	3 Residual Disinf. Conc. C (mg/L)	4 pH	5 Water Temp. (^{o}C)	6 Peak Hourly Flow (gpm)	7 Volume (gal)	8 TDT (min.)	9 Baffling Factor	10 Disinf. Contact Time T (min.)	11 $CT_{Calc} =$ (CxT) (min-mg/L)	12 CT Req'd (min-mg/L)	13 Inactivation Ratio (Col 11 / Col 12)	14 Log Inactivation*
1	0.6	N/A	10	5,000	31,000	6.2	1.0	6.2	3.7	1,850	0.002	
2												
3												
4												
5												
6												

*See worksheet #2 to determine total log inactivation if the system has multiple disinfection segments.

The worksheet excerpt below demonstrates how to determine total *Giardia* log inactivation for the system using Worksheet #2 in Appendix C.

WORKSHEET #2
TOTAL LOG INACTIVATION DETERMINATION FOR SURFACE WATER SYSTEMS OR
GROUND WATER SYSTEMS UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Starting Month: _January_ Year: _2004_ PWSID: _AA7654321_

System/Water Source: _ABC Water Plant_ Prepared by: _Jon Operator_

Disinfectant Type: _Chlorine/Chloramine_
Profile Type (check one): _X_ *Giardia* ____ Viruses

Week #	\multicolumn{5}{}{Inactivation Ratio for each disinfection segment from Worksheet #1}	Sum of Inactivation Ratios	Total Log Inactivation[1]
	Disinfection Segment 1	Disinfection Segment 2	Disinfection Segment 3	Disinfection Segment 4	Disinfection Segment 5		
1	0.137	0.365	0.002			0.504	1.51
2							
3							
4							
5							
6							

[1]*Giardia*: Log Inactivation = 3 x Sum of Inactivation Ratios
Viruses: Log Inactivation = 4 x Sum of Inactivation Ratios (or a method approved by the State)

Example D-3: Develop a Disinfection Profile and Benchmark for a System with Multiple Disinfection Segments

In this example a conventional filtration treatment plant added ozone in contact chambers at the front of the plant as a primary disinfectant and used chlorine as the secondary disinfectant after the clearwell. The ozone residual was measured at each ozone contact chamber and the chlorine residual was measured in the transmission pipe. The system was required to create a disinfection profile. Since ozone is used as a primary disinfectant, the system must calculate both *Giardia* and virus log inactivations.
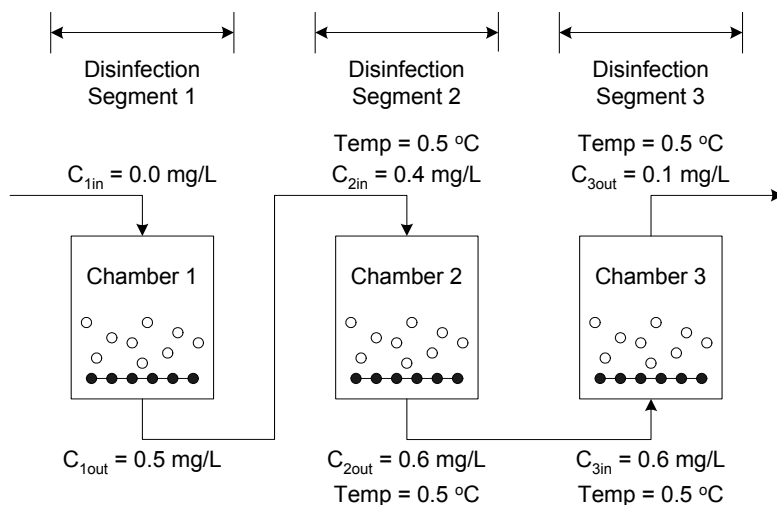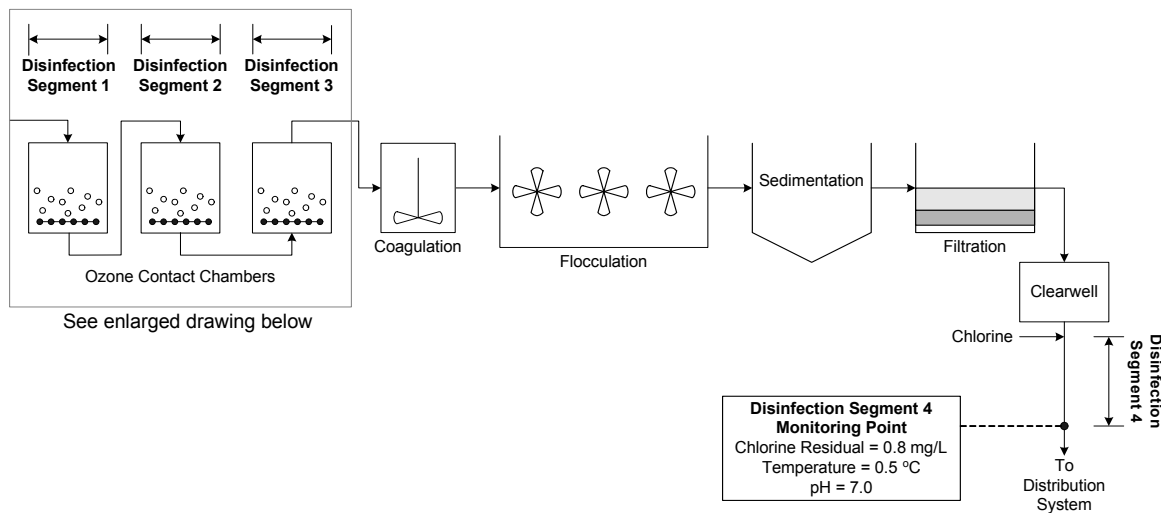
NOTE: Following is one method for calculating *Giardia* inactivation for ozone using the procedure presented in *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, March 1991). Systems must use a method approved by the State; therefore, systems should check with the State to determine if it approves this method or if another method is required.

Example D-3 continued

A. Determine the *Giardia* Log Inactivation for Disinfection Segment 1

Step 1. Measure the ozone residual at the inlet and outlet of Contact Chamber 1 during peak hourly flow.

$C_{1in} = 0.0$ mg/L
$C_{1out} = 0.5$ mg/L

Table D-1. Correlations to Predict C Based on Inlet and Outlet Ozone Concentrations

	Flow Configuration			
	Turbine	Co-Current Flow	Counter-Current Flow	Reactive Flow
First Chamber	C	Partial Credit[1]	Partial Credit[1]	Not Applicable
All Other Chambers	$C = C_{out}$	$C = C_{out}$ or $C = (C_{out} + C_{in}) / 2$	$C = C_{out} / 2$	$C = C_{out}$

1. 1-log of virus inactivation providing that $C_{out} > 0.1$ mg/L and 0.50 log *Giardia* inactivation providing that $C_{out} > 0.3$ mg/L.

(Source: *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, EPA, March 1991)

Step 2. Determine the* Giardia *log inactivation in Contact Chamber 1.

In Contact Chamber 1 the flow is counter-current since the water flows in the opposite direction that the ozone flows (Note: Ozone is introduced in the bottom of the chamber and bubbles upward). According to Table D-1, since the outlet ozone concentration is 0.5 mg/L, which is greater than 0.3 mg/L, **the *Giardia* log inactivation in Contact Chamber 1 is 0.50**.

B. Determine the *Giardia* Log Inactivation for Disinfection Segment 2

Step 1. Measure the temperature and the ozone residual at the inlet and outlet of Contact Chamber 2 during peak hourly flow.

Temperature $= 0.5$ ^oC
$C_{2in} = 0.4$ mg/L
$C_{2out} = 0.6$ mg/L

Example D-3 continued

Step 2. Determine C in Contact Chamber 2.

Table D-1. Correlations to Predict C Based on Inlet and Outlet Ozone Concentrations

Flow Configuration				
	Turbine	Co-Current Flow	Counter-Current Flow	Reactive Flow
First Chamber	C	Partial Credit[1]	Partial Credit[1]	Not Applicable
All Other Chambers	$C = C_{out}$	$C = C_{out}$ or $C = (C_{out} + C_{in}) / 2$	$C = C_{out} / 2$	$C = C_{out}$

1. 1-log of virus inactivation providing that $C_{out} > 0.1$ mg/L and 0.50 log *Giardia* inactivation providing that $C_{out} > 0.3$ mg/L.

(Source: *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, EPA, March 1991)

In Contact Chamber 2 the flow is counter-current since the water flows in the opposite direction that the ozone flows. According to Table D-1, $C = C_{out} / 2$ for contact chambers with counter-current flow.

$C = C_{2out} / 2$
$C = 0.6$ mg/L $/ 2$
$C = 0.3$ mg/L

Step 3. Determine the contact time in Contact Chamber 2.

The contact time for all of the ozone contact chambers taken together was determined by a tracer study to be 15 minutes at peak hourly flow. The total contact time can be divided proportionally by volume between all three chambers if the chambers with final concentrations of zero (non-detectable) do not make up 50% or greater of the total volume of the chambers. Since the final concentration in all chambers is greater than zero and since the contact chambers are all identical with equal volumes the contact time can be divided equally between all three chambers:

$T = T_{tot} / 3$ chambers $= 15$ min $/ 3$ chambers $=$ **5 minutes per chamber**

Example D-3 continued

Step 4. Calculate CT$_{calc}$ in Contact Chamber 2.

> CT$_{calc}$ = C x T
> CT$_{calc}$ = 0.3 mg/L x 5 min
> **CT$_{calc}$ = 1.5 min-mg/L**

Step 5. Locate appropriate CT table.

The table for 3-log inactivation of *Giardia* by ozone is Table B-5 in Appendix B.

Step 6. Identify the appropriate portion of the table based on operating conditions.

Locate the column for 0.5 °C (< = 1 ^{o}C).

Table B-5
CT Values for 3-Log Inactivation of *Giardia* Cysts by Ozone

Temperature (ºC)					
<u><= 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
2.9	1.90	1.43	0.95	0.72	0.48

Step 7. Obtain CT$_{99.9}$ value.

From this chart it is determined that the value of CT for 3-log inactivation by ozone at 0.5°C is 2.9 min-mg/L.

> **CT$_{99.9}$ = 2.9 min-mg/L**

Step 8. Calculate the **Giardia** *inactivation ratio for Disinfection Segment 2.*

> Inactivation ratio = CT$_{calc}$ / CT$_{99.9}$
> Inactivation ratio = (1.5 min-mg/L / 2.9 min-mg/L)
> **Inactivation ratio = 0.517**

Step 9. Calculate **Giardia** *inactivation for Disinfection Segment 2.*

> *Giardia* log inactivation = 3 x (CT$_{calc}$ / CT$_{99.9}$)
> *Giardia* log inactivation = 3 x 0.517
> ***Giardia* log inactivation = 1.55**

Example D-3 continued

C. Determine the *Giardia* Log Inactivation for Disinfection Segment 3

Step 1. Measure the temperature and the ozone residual at the inlet and outlet of Contact Chamber 3 during peak hourly flow.

Temperature = 0.5 $^{\circ}$C
C_{3in} = 0.6 mg/L
C_{3out} = 0.1 mg/L

Step 2. Determine C in Contact Chamber 3.

Table D-1. Correlations to Predict C Based on Inlet and Outlet Ozone Concentrations

Flow Configuration				
	Turbine	Co-Current Flow	Counter-Current Flow	Reactive Flow
First Chamber	C	Partial Credit[1]	Partial Credit[1]	Not Applicable
All Other Chambers	$C = C_{out}$	$C = C_{out}$ or $C = (C_{out} + C_{in}) / 2$	$C = C_{out} / 2$	$C = C_{out}$

1. 1-log of virus inactivation providing that C_{out} > 0.1 mg/L and 0.50 log *Giardia* inactivation providing that C_{out} > 0.3 mg/L.

(Source: *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, EPA, March 1991)

In Contact Chamber 3 the flow is co-current since the water flows in the same direction that the ozone flows. According to Table D-1, $C = (C_{out} + C_{in}) / 2$ for contact chambers with co-current flow.

$C = (C_{3in} + C_{3out}) / 2$
$C = (0.6$ mg/L $+ 0.1$ mg/L$) / 2$
C = 0.35 mg/L

Step 3. Determine the contact time in Contact Chamber 3.

It was determined in Part B, Step 3 of this example that the contact time in each chamber is 5 minutes.

T = 5 minutes

Example D-3 continued

Step 4. Calculate CT*calc* in Contact Chamber 3.

CT_{calc} = C x T
CT_{calc} = 0.35 mg/L x 5 min
CT_{calc} = 1.75 min-mg/L

Step 5. Locate appropriate CT table.

The table for 3-log inactivation of *Giardia* by ozone is Table B-5 in Appendix B.

Step 6. *Identify the appropriate portion of the table based on operating conditions.*

Locate the column for 0.5 °C ($< = 1\ ^{o}$C).

Table B-5
CT Values for 3-Log Inactivation of *Giardia* Cysts by Ozone

Temperature (ºC)					
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
2.9	1.90	1.43	0.95	0.72	0.48

Step 7. Obtain CT*99.9* value.

From this chart it is determined that the value of CT for 3-log inactivation by ozone at 0.5°C is 2.9 min-mg/L.

$CT_{99.9}$ = 2.9 min-mg/L

Step 8. Calculate the **Giardia** *inactivation ratio for Disinfection Segment 3.*

Inactivation ratio = CT_{calc} / $CT_{99.9}$
Inactivation ratio = (1.75 min-mg/L / 2.9 min-mg/L)
Inactivation ratio = 0.603

Step 9. Calculate **Giardia** *inactivation for Disinfection Segment 3.*

Giardia log inactivation = 3 x (CT_{calc} / $CT_{99.9}$)
Giardia log inactivation = 3 x 0.603
***Giardia* log inactivation = 1.81**

Example D-3 continued

D. Determine *Giardia* Log Inactivation for Disinfection Segment 4

Step 1. Determine the peak hourly flow.

From the raw water pump records the peak hourly flow (Q) is determined to be 5,000 gpm.
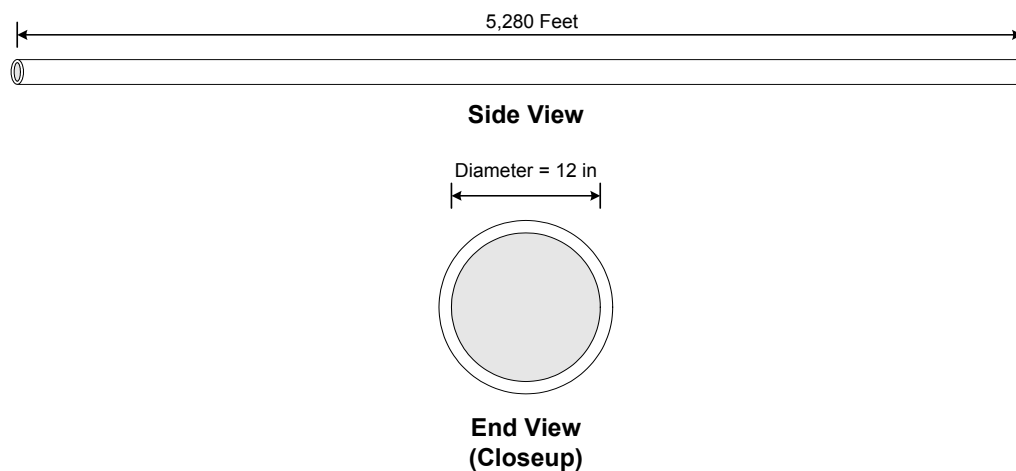
Step 2. Measure chlorine residual, temperature, and pH during peak hourly flow at the chlorine monitoring point and at the same time.

Temperature = 0.5 $^\circ$C
pH = 7.0
Chlorine residual = $C_{chlorine}$ = 0.8 mg/L

Step 3. Measure the physical dimensions of the pipe.

5,280 Feet

Side View

Diameter = 12 in

End View
(Closeup)

Measure the length of the pipe and the inner pipe diameter to obtain the volume of water in the pipe rather than the volume of the pipe itself.

Diameter = 12 in x (1 ft / 12 in) = 1.0 ft
Length = 5,280 ft

Step 4. Calculate the volume of the water in the pipe.

Volume (V) = π x Radius^2 x Length
π = 3.14 (constant)
Radius = Diameter / 2 = 1.0 / 2 = 0.5 ft
V = 3.14 x (0.5 ft)^2 x 5,280 ft = 4,140 ft^3
V = 4,140 ft^3 x (7.48 gal / ft^3)
V = 31,000 gallons

Example D-3 continued

Step 5. Calculate the Theoretical Detention Time in the pipe.

Theoretical Detention Time (TDT) = V / Q
TDT = 31,000 gal / 5,000 gpm
TDT = 6.2 minutes

Step 6. Determine the baffling factor for the pipe.

Baffling Factor (BF) = 1.0 (from Table G-1 in Appendix G for a pipe)

Step 7. Calculate the contact time of the disinfectant in the pipe.

Contact Time (T) = TDT x BF
T = 6.2 min x 1.0
T = 6.2 minutes

Step 8. Calculate the CT for the disinfection segment.

$CT_{calc} = C_{chlorine}$ x T
CT_{calc} = 0.8 mg/L x 6.2 min
CT_{calc} = 5.0 min-mg/L

Step 9. Determine the required $CT_{99.9}$ necessary to obtain 3-log Giardia inactivation.

The required CT value for 3-log *Giardia* inactivation ($CT_{99.9}$) is obtained by using CT Table B-1 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine. The $CT_{99.9}$ is 205 min-mg/L for a pH of 7.0, temperature of 0.5 ^{o}C, and $C_{chlorine}$ of 0.8 mg/L. The relevant section of Table B-1 is reprinted below and the pertinent section of the table is highlighted.

Excerpt from Table B-1:
CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine
(0.5 ^{o}C portion of table, for concentrations from 0.4 to 1.2 mg/L)

Chlorine Concentration (mg/L)	Temperature = 0.5 ^{o}C						
	pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	137	163	195	237	277	329	390
0.6	141	169	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451

Example D-3 continued

Step 10. Calculate the **Giardia** *inactivation ratio for the pipe.*

Inactivation ratio = CT_{calc} / $CT_{99.9}$
Inactivation ratio = (5.0 min-mg/L / 205 min-mg/L)
Inactivation ratio = 0.024

Step 11. Calculate the actual **Giardia** *log inactivation for the pipe.*

Log inactivation = 3 x CT_{calc} / $CT_{99.9}$
Log inactivation = 3 x 0.024
Log inactivation = 0.07

The log inactivation of *Giardia* for Disinfection Segment 4 is 0.07.

E. Calculate the Total *Giardia* Inactivation for the System

Step 1. Sum the **Giardia** *log inactivations for all of the disinfection segments to determine the total* **Giardia** *log inactivation achieved by the system.*

From Disinfection Segment 1:
    Giardia log inactivation = 0.50

From Disinfection Segment 2:
    Giardia log inactivation = 1.55

From Disinfection Segment 3:
    Giardia log inactivation = 1.81

From Disinfection Segment 4:
    Giardia log inactivation = 0.07

Total *Giardia* log inactivation = 0.50 + 1.55 + 1.81 + 0.07 = 3.93

Assuming the system received a 2.5 log *Giardia* removal credit from the State for conventional filtration, it must achieve at least 0.5 log *Giardia* inactivation for a total 3.0 log *Giardia* reduction as required in the Surface Water Treatment Rule (40 CFR Section 141.70(a)(1)). The value of 3.93 log *Giardia* inactivation exceeds the required 0.5 log *Giardia* inactivation.

Example D-3 continued

F. Determine Virus Log Inactivation for Disinfection Segment 1

Since ozone is used as a primary disinfectant in this system, the log inactivation for viruses must also be calculated.

Step 1. Determine the virus log inactivation in Contact Chamber 1.

Table D-1. Correlations to Predict C Based on Inlet and Outlet Ozone Concentrations

Flow Configuration				
	Turbine	Co-Current Flow	Counter-Current Flow	Reactive Flow
First Chamber	C	Partial Credit[1]	Partial Credit[1]	Not Applicable
All Other Chambers	$C = C_{out}$	$C = C_{out}$ or $C = (C_{out} + C_{in}) / 2$	$C = C_{out} / 2$	$C = C_{out}$

1. 1-log of virus inactivation providing that $C_{out} > 0.1$ mg/L and 0.50 log *Giardia* inactivation providing that $C_{out} > 0.3$ mg/L.

(Source: *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, EPA, March 1991)

> In Contact Chamber 1 the flow is counter-current since the water flows in the opposite direction that the ozone flows (Note: Ozone is introduced in the bottom of the chamber and bubbles upward). According to Table D-1, since the outlet ozone concentration is 0.5 mg/L (determined in Part A of this Example), which is greater than 0.1 mg/L, **the virus log inactivation in Disinfection Segment 1 (Contact Chamber 1) is 1.0**.

G. Determine Virus Log Inactivation for Disinfection Segment 2

Step 1. Determine the required $CT_{99.99}$ necessary to obtain 4-log virus inactivation for Contact Chamber 2.

The required CT value for 4-log virus inactivation ($CT_{99.99}$) is obtained by using CT Table B-6 in Appendix B, CT Values for 4-Log Inactivation of Viruses by Ozone. In this example the required $CT_{99.99}$ is 1.8 min-mg/L for a temperature of 0.5 ^{o}C.

Example D-3 continued

Table B-6
CT Values for 4-Log Inactivation of Viruses by Ozone

		Temperature (^oC)			
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
1.8	1.2	1.0	0.6	0.5	0.3

Step 2. Calculate the virus inactivation ratio for Contact Chamber 2.

CT_{calc} has already been calculated for Disinfection Segment 2.
$CT_{calc} = 1.5$ min-mg/L

Inactivation ratio = CT_{calc} / $CT_{99.9}$
Inactivation ratio = (1.5 min-mg/L / 1.8 min-mg/L)
Inactivation ratio = 0.833

Step 3. Calculate the virus inactivation for Contact Chamber 2.

Virus log inactivation = 4 x CT_{calc} / $CT_{99.99}$
Virus log inactivation = 4 x 0.833
Virus log inactivation = 3.3

The log inactivation of viruses for Disinfection Segment 2 is 3.3.

H. Determine Virus Log Inactivation for Disinfection Segment 3

Step 1. Determine the required $CT_{99.99}$ necessary to obtain 4-log virus inactivation for Contact Chamber 3.

The required CT value for 4-log virus inactivation ($CT_{99.99}$) is obtained by using CT Table B-6 in Appendix B, CT Values for 4-Log Inactivation of Viruses by Ozone. The required $CT_{99.99}$ is 1.8 min-mg/L for a temperature of 0.5 ^oC.

Table B-6
CT Values for 4-Log Inactivation of Viruses by Ozone

		Temperature (^oC)			
<u>< = 1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
1.8	1.2	1.0	0.6	0.5	0.3

Example D-3 continued

Step 2. Calculate the virus inactivation ratio for Contact Chamber 3.

CT_{calc} has already been calculated for Disinfection Segment 3.
CT_{calc} = 1.75 min-mg/L

Inactivation ratio = CT_{calc} / $CT_{99.9}$
Inactivation ratio = (1.75 min-mg/L / 1.8 min-mg/L)
Inactivation ratio = 0.972

Step 3. Calculate the actual virus log inactivation for Contact Chamber 3.

Log inactivation = 4 x CT_{calc} / $CT_{99.99}$
Log inactivation = 4 x 0.972
Log inactivation = 3.9

The log inactivation of viruses for Disinfection Segment 3 is 3.9.

I. Determine Virus Log Inactivation for Disinfection Segment 4.

Even though chlorine is the only disinfectant used in Disinfection Segment 4, the virus inactivation for Disinfection Segment 4 must also be calculated to determine the virus inactivation for the whole system.

Step 1. Determine the required $CT_{99.99}$ necessary to obtain 4-log virus inactivation for Disinfection Segment 4.

The required CT value for 4-log virus inactivation ($CT_{99.99}$) is obtained by using CT Table B-2 in Appendix B, CT Values for 4-log Inactivation of Viruses by Free Chlorine. The required $CT_{99.99}$ is 12 min-mg/L for a pH of 7.0 and temperature of 0.5 ^{o}C. Table B-2 is reprinted on the next page and the pertinent section of the table is highlighted.

Table B-2:
CT Values for 4-Log Inactivation of Viruses by Free Chlorine

	pH	
Temperature (^{o}C)	6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

Example D-3 continued

Step 2. Calculate the virus inactivation ratio for Disinfection Segment 4.

CT_{calc} has already been calculated for Disinfection Segment 4.
$CT_{calc} = 5.0$ min-mg/L

Inactivation ratio $= CT_{calc} / CT_{99.9}$
Inactivation ratio $= (5.0$ min-mg/L $/ 12$ min-mg/L$)$
Inactivation ratio $= 0.417$

Step 3. Calculate the actual virus log inactivation for Disinfection Segment 4.

Log inactivation $= 4 \times CT_{calc} / CT_{99.99}$
Log inactivation $= 4 \times 0.417$
Log inactivation $= 1.7$

J. Calculate the Total Virus Inactivation for the System

Sum the virus log inactivations for all of the Disinfection Segments to determine the total virus log inactivation achieved by the system.

From Disinfection Segment 1:
virus log inactivation = 1.0

From Disinfection Segment 2:
virus log inactivation = 3.3

From Disinfection Segment 3:
virus log inactivation = 3.9

From Disinfection Segment 4:
virus log inactivation = 1.7

Total virus log inactivation = 1.0 + 3.3 + 3.9 + 1.7 = 9.9

Assuming the system received a 2.0 log virus removal credit from the State for conventional filtration, it must achieve at least 2.0 log virus inactivation for a total 4.0 log virus reduction as required in the Surface Water Treatment Rule (40 CFR Section 141.70(a)(2)). The value of 9.9 log virus inactivation exceeds the required 2.0 log virus inactivation.

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Appendix E
Tracer Studies

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E.1 INTRODUCTION

Information in this appendix is based on Appendix C in the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991). For more information on tracer studies, readers are encouraged to consult Appendix C in the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991) or *Tracer Studies in Water Treatment Facilities: A Protocol and Case Studies* (Teefy, 1996).

As indicated in Chapter 4, fluid passing through a pipe is assumed to have a detention time equal to the theoretical or mean residence time at a particular flow rate. However, in mixing basins, storage reservoirs, and other treatment plant process units, utilities will be required to determine the contact time for the calculation of CT through tracer studies or other methods approved by the State.

The contact time of mixing basins and storage reservoirs used in calculating CT should be the minimum detention time experienced by 90 percent of the water passing through the unit. This detention time was designated as T_{10} according to the convention adopted by Thirumurthi (1969). A profile of the flow through the basin over time can be generated by tracer studies. Information provided by these studies may be used for estimating the detention time, T_{10}, for the purpose of calculating CT. **(Note: T_{10} is referred to as "T" elsewhere in this document. However, for consistency with the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991), T_{10} is used in this appendix.)**

This appendix presents a brief synopsis of tracer study methods, procedures, and data evaluation. More detailed information about conducting tracer studies is available in Appendix C of the lengthier *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991). It is important to obtain assistance from the State before conducting a tracer study to ensure State approval of the results.

E.2 FLOW EVALUATION

Although detention time is proportional to flow, it is not generally a linear function. Tracer studies may establish detention times for the range of flow rates experienced within each disinfectant segment. Systems should note that a single flow rate might not characterize the flow through the entire system. With a series of reservoirs, clearwells, and storage tanks, flow will vary between each portion of the system.

Ideally, tracer tests should be performed for at least four flow rates that span the entire range of flow for the segment being tested. The flow rates should be separated by approximately equal intervals to span the range of operation, with one near average flow, two greater than average, and one less than average flow. The flows should also be selected so that the

highest test flow rate is at least 91 percent of the highest flow rate expected to ever occur in that segment. Four data points should assure a good definition of the segment's hydraulic profile.

The results of the tracer tests performed for different flow rates should be used to generate plots of T_{10} versus flow (Q) for each segment in the system. A smooth line is drawn through the points on each graph to create a curve from which T_{10} may be read for the corresponding flow at peak hourly flow conditions. Refer to Appendix C, section C.1.7 of the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991), for an illustration of this procedure.

The most accurate tracer test results are obtained when flow is constant through the segment during the course of the test. Therefore, the tracer study should be conducted at a constant flow whenever practical. For a treatment plant consisting of two or more equivalent process trains, a constant flow tracer test can be performed on a segment of the plant by holding the flow through one of the trains constant while operating the parallel train(s) to absorb any flow variations. Flow variations during tracer tests in systems without parallel trains or with single clearwells and storage reservoirs are more difficult to avoid. In these instances, T_{10} should be recorded at the average flow rate over the course of the test.

E.3 VOLUME EVALUATION

In addition to flow conditions, detention times determined by tracer studies depend on the water level and subsequent volume in treatment units. This is particularly pertinent to storage tanks, reservoirs, and clearwells, which, in addition to being contact basins for disinfection are also often used as equalization storage for distribution system demands and storage for backwashing. In such instances, the water levels in the reservoirs vary to meet the system demands. The actual detention time of these contact basins will also vary depending on whether they are emptying or filling.

For some process units, especially sedimentation basins that are operated at a near constant level (that is, flow in equals flow out), the detention time determined by tracer tests should be sufficient for calculating CT when the basin is operating at water levels greater than or equal to the level at which the test was performed. When conducting a tracer study to determine the detention time, a water level at or slightly below, but not above, the normal minimum operating level is recommended. For many plants, the water level in a clearwell or storage tank varies between high and low levels in response to distribution system demands. In such instances, in order to obtain a conservative estimate of the contact time, the tracer study should be conducted during a period when the tank level is falling (flow out greater than flow in).

E.4 DISINFECTION SEGMENTS

For systems that apply disinfectant(s) at more than one point, or choose to profile the residual from one point of application, tracer studies should be conducted to determine T_{10} for each segment containing process unit(s). The T_{10} for a segment may or may not include a length of pipe and is used along with the residual disinfectant concentration prior to the next disinfectant application or monitoring point to determine the CT_{calc} for that segment. The inactivation ratio for the section is then determined. The total log inactivation achieved in the system can then be determined by summing the inactivation ratios for all sections as explained in Chapter 5 of this document.

For systems that have two or more units of identical size and configuration, tracer studies could be conducted on one of the units but applied to both. The resulting graph of T_{10} versus flow can be used to determine T_{10} for all identical units.

Systems with more than one segment in the treatment plant that are conducting a tracer study may determine T_{10} for each segment:

- By individual tracer studies through each segment; or,

- By one tracer study across the system.

If possible, tracer studies should be conducted on each segment to determine the T_{10} for each segment. In order to minimize the time needed to conduct studies on each segment, the tracer studies should be started at the last segment of the treatment train prior to the first customer and completed with the first segment of the system. Conducting the tracer studies in this order will prevent the interference of residual tracer material with subsequent studies.

For ozone contactors, flocculators, or any basin containing mixing, tracer studies should be conducted for the range of mixing used in the process. In ozone contactors, air or oxygen should be added in lieu of ozone to prevent degradation of the tracer. The flow rate of air or oxygen used for the contactor should be applied during the study to simulate actual operation. Tracer studies should then be conducted at several air/oxygen to water ratios to provide data for the complete range of ratios used at the plant. For flocculators, tracer studies should be conducted for various mixing intensities to provide data for the complete range of operations.

E.5 TRACER STUDY METHODS

This section discusses the two most common methods of tracer addition employed in water treatment evaluations, the step-dose method and the slug-dose method. Tracer study methods involve the application of chemical dosages to a system, and tracking the resulting effluent concentration as a function of time. The effluent concentration profile is evaluated to determine the detention time, T_{10}.

In preparation for beginning a tracer study, the raw water background concentration of the

chosen tracer chemical should be established. The background concentration is important, not only to aid in the selection of the tracer dosage, but also to facilitate proper evaluation of the data.

The background tracer concentration should be determined by monitoring for the tracer chemical prior to beginning the test. The sampling point(s) for the pre-tracer study monitoring should be the same as the points to be used for residual monitoring to determine CT values. Systems should use the following monitoring procedure:

- Prior to the start of the test, regardless of whether the chosen tracer material is a treatment chemical, the tracer concentration in the water is monitored at the sampling point where the disinfectant residual will be measured for CT calculations.

- If a background tracer concentration is detected, monitor it until a constant concentration, at or below the raw water background level, is achieved. This measured concentration is the baseline tracer concentration.

Following the determination of the tracer dosage, feed and monitoring point(s), and a baseline tracer concentration, tracer testing can begin.

Equal sampling intervals, as could be obtained from automatic sampling, are not required for either tracer study method. However, using equal sample intervals for the slug-dose method can simplify the analysis of the data. During testing, the time and tracer residual of each measurement should also be recorded on a data sheet. In addition, the water level, flow, and temperature should be recorded during the test.

E.5.1 Step-Dose Method

The step-dose method entails introduction of a tracer chemical at a constant dosage until the concentration at the desired end point reaches a steady-state level. At time zero, the tracer chemical feed is started and left at a constant rate for the duration of the test. Over the course of the test, the tracer residual should be monitored at the required sampling point(s) at a frequency determined by the overall detention time and site-specific considerations. As a general guideline, sampling at intervals of 2 to 5 minutes should provide data for a well-defined plot of tracer concentration versus time. If on-site analysis is available, less frequent residual monitoring may be possible until a change in residual concentration is first detected. Regular sampling is continued until the residual concentration reaches a steady-state value.

One graphical method of evaluating step-dose test data involves plotting a graph of dimensionless concentration (tracer concentration (C) / applied tracer concentration (C_o)) versus time and reading the value for T_{10} directly from the graph at the appropriate dimensionless concentration. Alternatively, the data from step-dose tracer studies may be evaluated numerically by developing a semi-logarithmic plot of the dimensionless data. The semi-logarithmic plot allows a straight line to be drawn through the data. The resulting equation of the line is used to calculate the T_{10} value, assuming that the correlation coefficient indicates a good statistical fit (0.9 or above). Drawing a smooth curve through the data discredits scattered data points from step-dose tracer tests.

Step-dose tracer studies are frequently employed in drinking water applications for the following reasons:

- The resulting normalized concentration versus time profile is directly used to determine T_{10}, the detention time required for calculating CT; and,

- Very often, the necessary feed equipment is available to provide a constant rate of application of the tracer chemical.

One other advantage of the step-dose method is that the data may be verified by comparing the concentration versus elapsed time profile for samples collected at the start of dosing with the profile obtained when the tracer feed is discontinued.

E.5.2 Slug-Dose Method

In the slug-dose method, a large instantaneous dose of tracer is added to the incoming water and samples are taken at the exit of the unit over time as the tracer passes through the unit. At time zero for the slug-dose method, a large instantaneous dose of tracer is added to the influent of the unit. The same sampling locations and frequencies described for step-dose method tests also apply to slug-dose method tracer studies. One exception with this method is that the tracer concentration profile will not equilibrate to a steady-state concentration. Because of this, the tracer should be monitored frequently enough to ensure acquisition of data needed to identify the peak tracer concentration.

Slug-dose method tests should be checked by performing a material balance to ensure that all of the tracer fed is recovered, or mass applied equals mass discharged.

Data from slug-dose tracer tests may be analyzed by converting it to the mathematically equivalent step-dose data and using the techniques discussed above for the step-dose method to determine T_{10}. A graph of dimensionless concentration versus time should be drawn which represents the results of a slug-dose tracer test. The key to converting between the data forms is obtaining the total area under the slug-dose data curve. This area is found by integrating the curve graphically or numerically. The conversion to step-dose data is then completed in several mathematical steps involving the total area.

Slug-dose concentration profiles can have many shapes, depending on the hydraulics of the basin. Therefore, slug-dose data points should not be discredited by drawing a smooth curve through the data prior to its conversion to step-dose data.

A disadvantage of the slug-dose method is that very concentrated solutions are needed for the dose in order to adequately define the concentration versus time profile. Intensive mixing is therefore necessary to minimize potential density-current effects and to obtain a uniform distribution of the instantaneous tracer dose across the basin. This is inherently difficult under water flow conditions often existing at inlets to basins. Other disadvantages of using the slug-dose method include:

- The concentration and volume of the instantaneous tracer dose needs to be carefully computed to provide an adequate tracer profile at the effluent of the basin;

- The resulting concentration versus time profile should not be used to directly determine T_{10} without further manipulation; and,

- A mass balance on the treatment segment should be used to determine whether the tracer was completely recovered.

One advantage of this method is that it may be applied where chemical feed equipment is not available at the desired point of addition, or where the equipment available does not have the capacity to provide the necessary concentration of the chosen tracer chemical. Although, in general, the step-dose procedure offers the greatest simplicity, both methods are theoretically equivalent for determining T_{10}. Either method or another method may be used for conducting drinking water tracer studies, and the choice of method may be determined by site-specific constraints or the system's experience.

E.6 TRACER SELECTION

An important step in any tracer study is the selection of a chemical to be used as the tracer. Ideally, the selected tracer chemical should be readily available, conservative (that is, not consumed or removed during treatment), easily monitored, and acceptable for use in potable water supplies. Chloride and fluoride are the most common tracer chemicals employed in drinking water plants that are nontoxic and approved for potable water use. Rhodamine WT can be used as a fluorescent tracer in water flow studies in accordance with the following guidelines:

- Raw water concentrations should be limited to a maximum concentration of 10 mg/L;

- Drinking water concentrations should not exceed 0.1 μg/L;

- Studies that result in human exposure to the dye should be brief and infrequent; and,

- Concentrations as low as 2 μg/L can be used in tracer studies because of the low detection level in the range of 0.1 to 0.2 μg/L.

The use of Rhodamine B as a tracer in water flow studies is not recommended by the EPA.

The choice of a tracer chemical can be made based, in part, on the selected dosing method and on the availability of chemical feeding equipment. For example, the high density of concentrated salt solutions and their potential for inducing density currents usually precludes chloride and fluoride as the selected chemical for slug-dose tracer tests.

Fluoride can be a convenient tracer chemical for step-dose tracer tests of clearwells because it is frequently applied for finished water treatment. However, when fluoride is used in tracer tests on clarifiers, allowances should be made for fluoride that is absorbed on floc and settles out of water (Hudson, 1975). Additional considerations when using fluoride in tracer studies include:

- It is difficult to detect at low levels,

- Many states impose a finished water limitation of 1 mg/L; and,

- The federal secondary and primary drinking water standards (i.e., the MCLs) for fluoride are 2 and 4 mg/L, respectively.

For safety reasons, particularly for people on dialysis, fluoride is not recommended for use as a tracer in systems that normally do not fluoridate their water. The use of fluoride is only recommended in cases where the feed equipment is already in place. The system may wish to turn off the fluoride feed in the plant for 12 or more hours prior to beginning the fluoride feed for the tracer study. Flushing out fluoride residuals from the system prior to conducting the tracer study is recommended to reduce background levels and avoid spiked levels of fluoride that might exceed EPA's MCL or SMCL for fluoride in drinking water. In instances where only one of two or more parallel units is tested, flow from the other units would dilute the tracer concentration prior to leaving the plant and entering the distribution system. Therefore, the impact of drinking water standards on the use of fluoride and other tracer chemicals can be alleviated in some cases.

E.7 REFERENCES

EPA. 1991. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources*. Washington, D.C.

Hudson, H.E., Jr. 1975. Residence Times in Pretreatment. Journal AWWA, 67(1): 45-52.

Teefy, Susan. 1996. *Tracer Studies in Water Treatment Facilities: A Protocol and Case Studies*. American Water Works Association Research Foundation. Denver, CO.
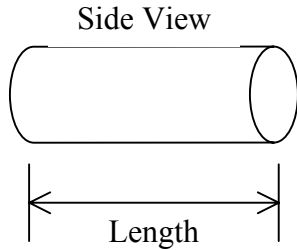
Appendix F
Calculating the Volume of Each Sub-Unit

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Note: If dimensions are in feet and the volume is calculated in cubic feet, then the volume should be converted to gallons by using the conversion: $1 \text{ ft}^3 = 7.48$ gal.

Water Pipe (raw or treated):
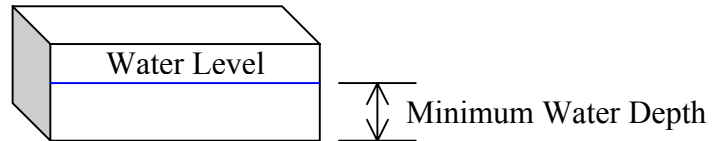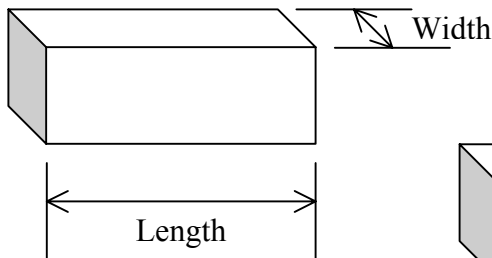Fluid Volume = Length x Cross-Sectional Area (Assumes full-pipe flow)

Side View

Cross-Section View
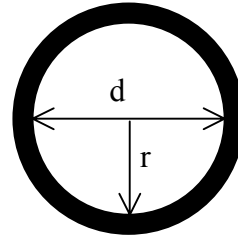
Cross-Sectional Area = $3.1416 * r^2$
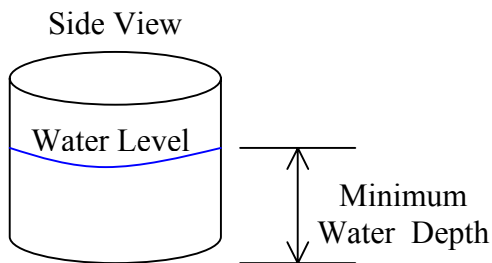r = inner radius = d / 2
d = inner diameter

Rectangular Basin:
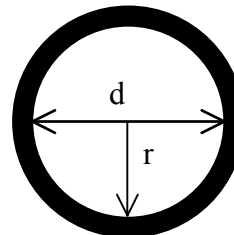Fluid Volume = Length x Width x Minimum Water Depth

Width

Water Level

Length

Minimum Water Depth

Cylindrical Basin:
Fluid Volume = Minimum Water Depth x Cross-Sectional Area

Side View

Top View

Water Level

Minimum Water Depth
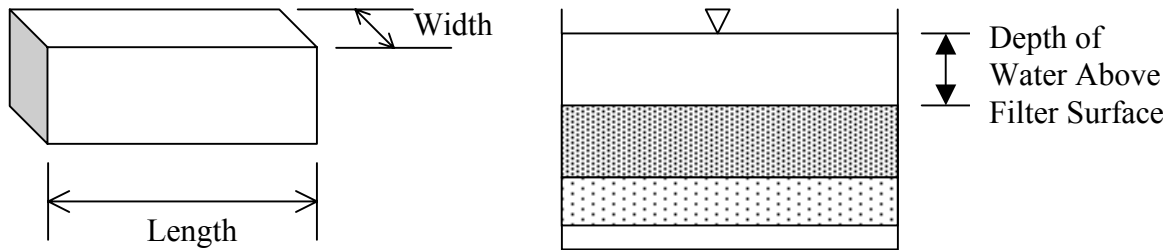
Cross-Sectional Area = $3.1416 * r^2$
r = inner radius = d / 2
d = inner diameter

Filters
Fluid Volume = Volume of Water Above Filter Surface
            = Length x Width x Depth of Water Above Filter Surface

Note: Some States may give credit for volume in media. Check with the State for the appropriate method to use for calculating volume in media.

Appendix G
Baffling Factors

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G.1 INTRODUCTION

Information in this appendix is based on Appendix C in the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991). References to the main body of the report, section headers, and some terminology have been modified to relate better to the content of this Disinfection Profiling and Benchmarking Technical Guidance Manual. **(Note: T_{10} is referred to as "T" elsewhere in this document. However, for consistency with the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA, 1991), T_{10} is used in this appendix.)**

In some situations, conducting tracer studies for determining the disinfectant contact time, T_{10}, may be impractical or prohibitively expensive. The limitations may include a lack of funds, personnel, or equipment necessary to conduct the study. States may allow the use of "rule of thumb" fractions representing the ratio of T_{10} to T, and the theoretical detention time (TDT), to determine the detention time, T_{10}, to be used for calculating CT values. This method for finding T_{10} involves multiplying the TDT by the rule of thumb fraction, T_{10}/T, which is representative of the particular basin configuration for which T_{10} is desired. These fractions provide rough estimates of the actual T_{10} and systems should coordinate with their State when selecting a baffling factor.

Tracer studies conducted by Marske and Boyle (1973) and Hudson (1975) on chlorine contact chambers and flocculators/settling basins, respectively, were used as a basis in determining representative T_{10}/T values for various basin configurations. Marske and Boyle (1973) performed tracer studies on 15 distinctly different types of full-scale chlorine contact chambers to evaluate design characteristics that affect the actual detention time. Hudson (1975) conducted 16 tracer tests on several flocculation and settling basins at six water treatment plants to identify the effect of flocculator baffling and settling basin inlet and outlet design characteristics on the actual detention time.

G.2 IMPACT OF DESIGN CHARACTERISTICS

The significant design characteristics include length-to-width ratio, the degree of baffling within the basins, and the effect of inlet baffling and outlet weir configuration. These physical characteristics of the contact basins affect their hydraulic efficiencies in terms of dead space, plug flow, and mixed flow proportions. The dead space zone of a basin is basin volume through which no flow occurs. The remaining volume where flow occurs is comprised of plug flow and mixed flow zones. The plug flow zone is the portion of the remaining volume in which no mixing occurs in the direction of flow. The mixed flow zone is characterized by complete mixing in the flow direction and is the complement to the plug flow zone. All of these zones were identified in the studies for each contact basin. Comparisons were then made between the basin configurations and the observed flow conditions and design characteristics.

The ratio T_{10}/T was calculated from the data presented in the studies and compared to its associated hydraulic flow characteristics. Both studies resulted in T_{10}/T values that ranged from 0.3 to 0.7. The results of the studies indicate how basin baffling conditions can influence the T_{10}/T ratio, particularly baffling at the inlet and outlet to the basin. As the basin baffling conditions improved, higher T_{10}/T values were observed, with the outlet conditions generally having a greater impact than the inlet conditions.

As discovered from the results of the tracer studies performed by Marske and Boyle (1973) and Hudson (1975), the effectiveness of baffling in achieving a high T_{10}/T fraction is more related to the geometry and baffling of the basin than the function of the basin. For this reason, T_{10}/T values may be defined for five levels of baffling conditions rather than for particular types of contact basins. General guidelines were developed relating the T_{10}/T values from these studies to the respective baffling characteristics. These guidelines can be used to determine the T_{10} values for specific basins.

G.3 BAFFLING CLASSIFICATIONS

The purpose of baffling is to maximize utilization of basin volume, increase the plug flow zone in the basin, and minimize short circuiting. Some form of baffling at the inlet and outlet of the basins is used to evenly distribute flow across the basin. Additional baffling may be provided within the interior of the basin (intra-basin) in circumstances requiring a greater degree of flow distribution. Ideal baffling design reduces the inlet and outlet flow velocities, distributes the water as uniformly as practical over the cross section of the basin, minimizes mixing with the water already in the basin, and prevents entering water from short circuiting to the basin outlet as the result of wind or density current effects. Five general classifications of baffling conditions – unbaffled, poor, average, superior, and perfect (plug flow) - were developed to categorize the results of the tracer studies for use in determining T_{10} from the TDT of a specific basin. The T_{10}/T fractions associated with each degree of baffling are summarized in Table G-1. Factors representing the ratio between T_{10} and the TDT for plug flow in pipelines and flow in a completely mixed chamber have been included in Table G-1 for comparative purposes. However, in practice the theoretical T_{10}/T values of 1.0 for plug flow and 0.1 for mixed flow are seldom achieved because of the effect of dead space. Conversely, the T_{10}/T values shown for the intermediate baffling conditions already incorporate the effect of the dead space zone, as well as the plug flow zone, because they were derived empirically rather than from theory.

Table G-1. Baffling Classifications

Baffling Condition	T10/T	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles.
Average	0.5	Baffled inlet or outlet with some intra-basin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders.
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles.

As indicated in Table G-1, <u>poor</u> baffling conditions consist of an unbaffled inlet and outlet with no intra-basin baffling. <u>Average</u> baffling conditions consist of intra-basin baffling and either a baffled inlet or outlet. <u>Superior</u> baffling conditions consist of at least a baffled inlet and outlet, and intra-basin baffling to redistribute the flow throughout the basin's cross-section.

The three basic types of basin inlet baffling configurations are a target-baffled pipe inlet, an overflow weir entrance, and a baffled submerged orifice or port inlet. Typical intra-basin baffling structures include diffuser (perforated) walls; launders; cross, longitudinal, or maze baffling to cause horizontal and/or vertical serpentine flow; and longitudinal divider walls, which prevent mixing by increasing the length-to-width ratio of the basin(s). Commonly used baffled outlet structures include free-discharging weirs, such as sharp-crested and multiple V-notch, and submerged ports or weirs. Weirs that do not span the width of the contact basin, such as Cipolleti weirs, should not be considered baffling as their use may substantially increase weir overflow rates and the dead space zone of the basin.

G.4 EXAMPLES OF BAFFLING

Examples of these levels of baffling conditions for rectangular and circular basins are explained and illustrated in this section. Typical uses of various forms of baffled and unbaffled inlet and outlet structures are also illustrated.

The plan and section of a rectangular basin with <u>poor</u> baffling conditions, which can be attributed to the unbaffled inlet and outlet pipes, are illustrated in Figure G-1. The flow pattern shown in the plan view indicates straight-through flow with dead space occurring in the regions between the individual pipe inlets and outlets. The section view reveals additional dead space from a vertical perspective in the upper inlet and lower outlet corners

of the contact basin. Vertical mixing also occurs as bottom density currents induce a counter-clockwise flow in the upper water layers.

The inlet flow distribution is markedly improved by the addition of an inlet diffuser wall and intra-basin baffling as shown in Figure G-2. However, only <u>average</u> baffling conditions are achieved for the basin as a whole because of the inadequate outlet structure - a Cipolleti weir. The width of the weir is short in comparison with the width of the basin. Consequently, dead space exists in the corners of the basin, as shown by the plan view. In addition, the small weir width causes a high weir overflow rate, which results in short circuiting in the center of the basin.

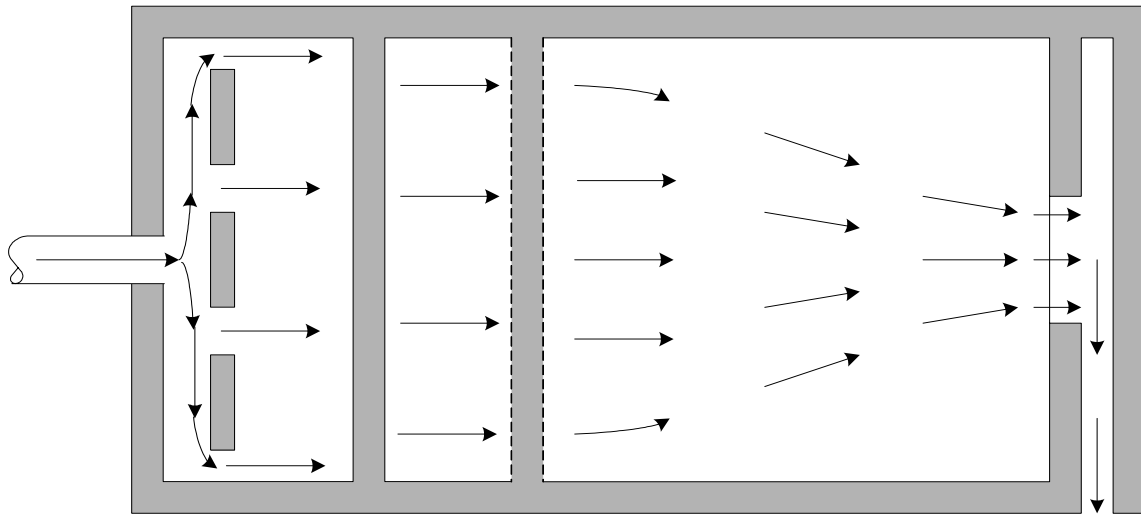**Figure G-1. Poor Baffling Conditions- Rectangular Contact Basin**
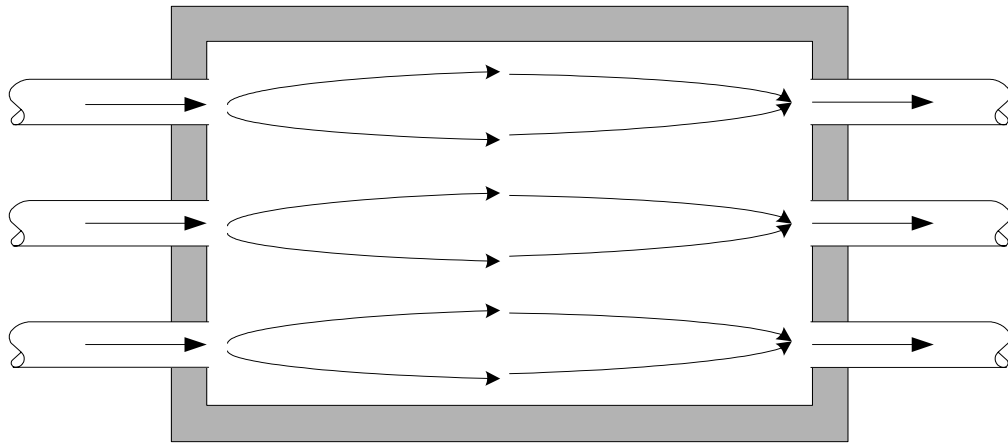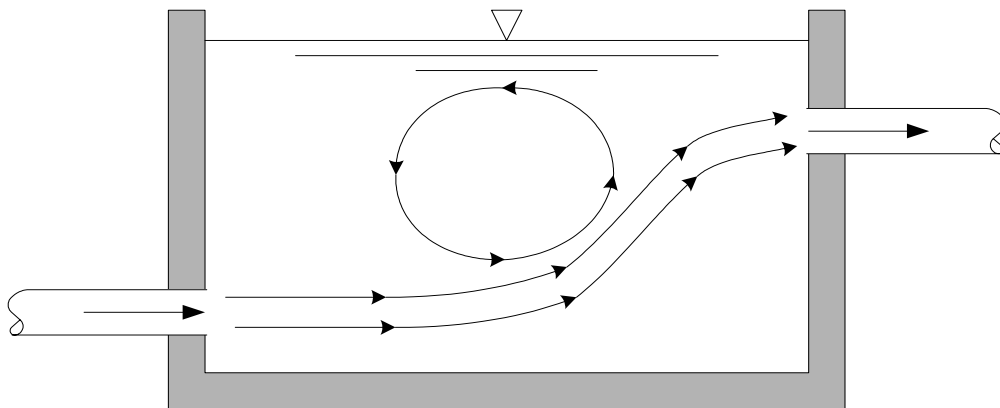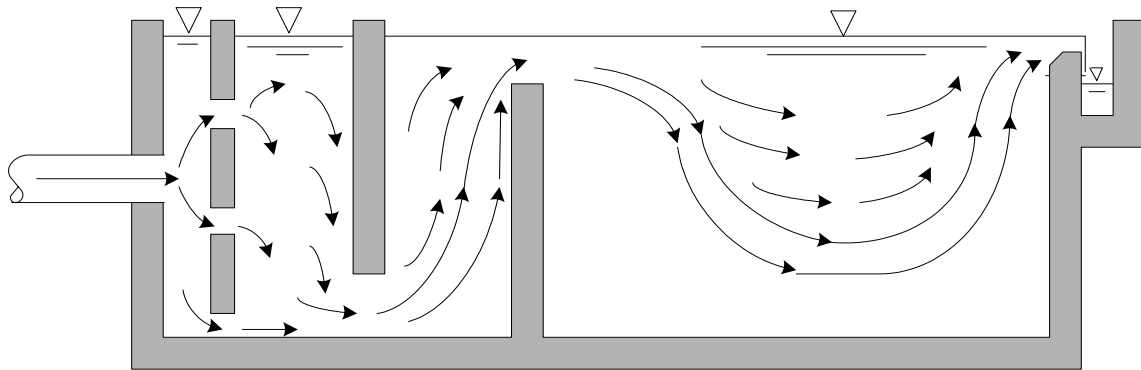

Plan View

Section View

**Figure G-2. Average Baffling Conditions- Rectangular Contact Basin**

Plan View

Section View

Superior baffling conditions are exemplified by the flow pattern and physical characteristics of the basin shown in Figure G-3. The inlet to the basin consists of submerged, target-baffled ports. This inlet design serves to reduce the velocity of the incoming water and distribute it uniformly throughout the basin's cross-section. The outlet structure is a sharp-crested weir that extends for the entire width of the contact basin. This type of outlet structure will reduce short circuiting and decrease the dead space fraction of the basin, although the overflow weir does create some dead space at the lower corners of the effluent end.

Figure G-3. Superior Baffling Conditions- Rectangular Contact Basin

Plan View

Section View
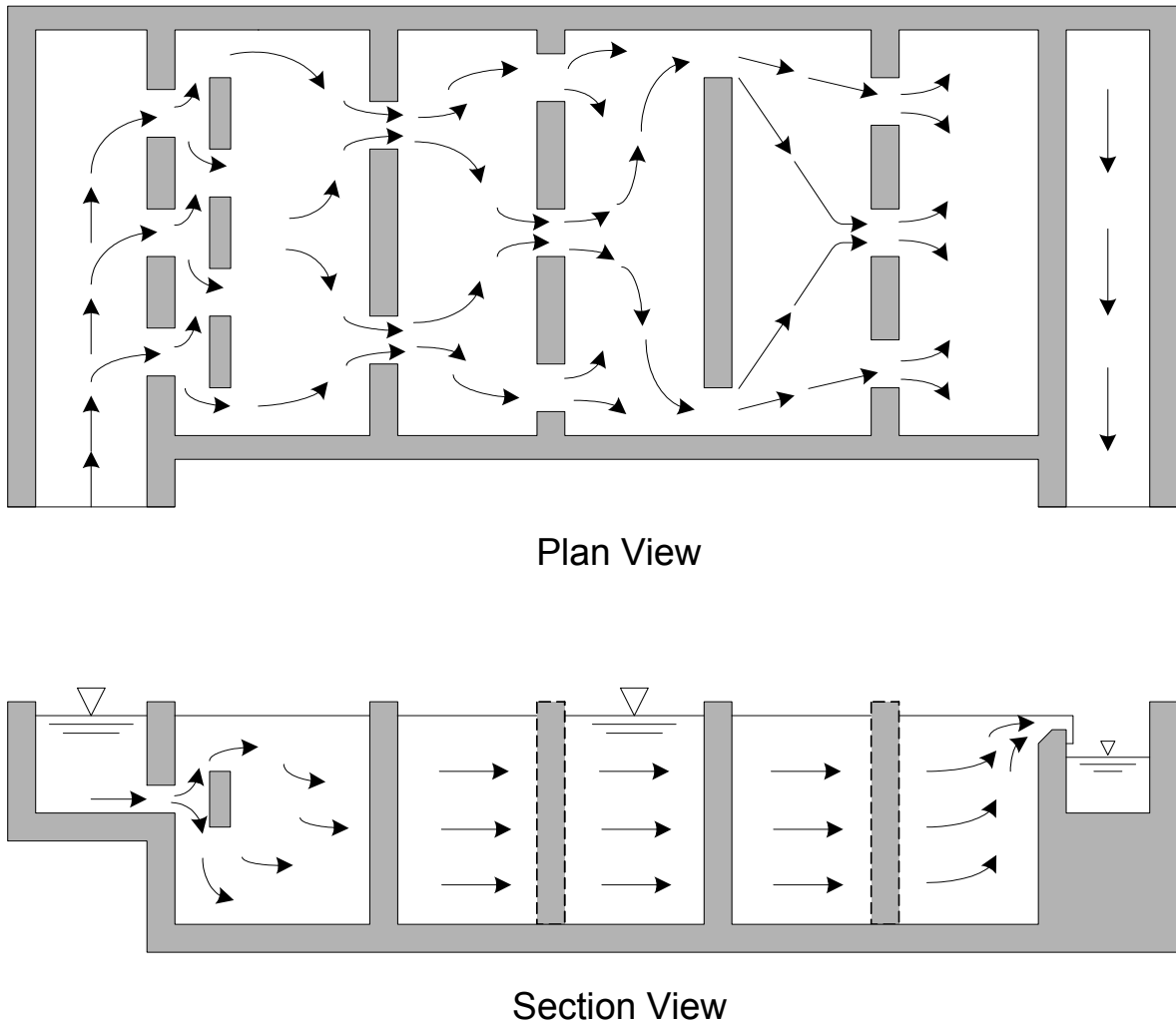
The plan and section of a circular basin with <u>poor</u> baffling conditions, which can be attributed to flow short circuiting from the center feed well directly to the effluent trough are shown in Figure G-4. Short circuiting occurs in spite of the outlet weir configuration because the center feed inlet is not baffled. The inlet flow distribution is improved somewhat in Figure G-5 by the addition of an annular ring baffle at the inlet which causes the inlet flow to be distributed throughout a greater portion of the basin's available volume. However, the baffling conditions in this contact basin are only <u>average</u> because the inlet center feed arrangement does not entirely prevent short circuiting through the upper levels of the basin.

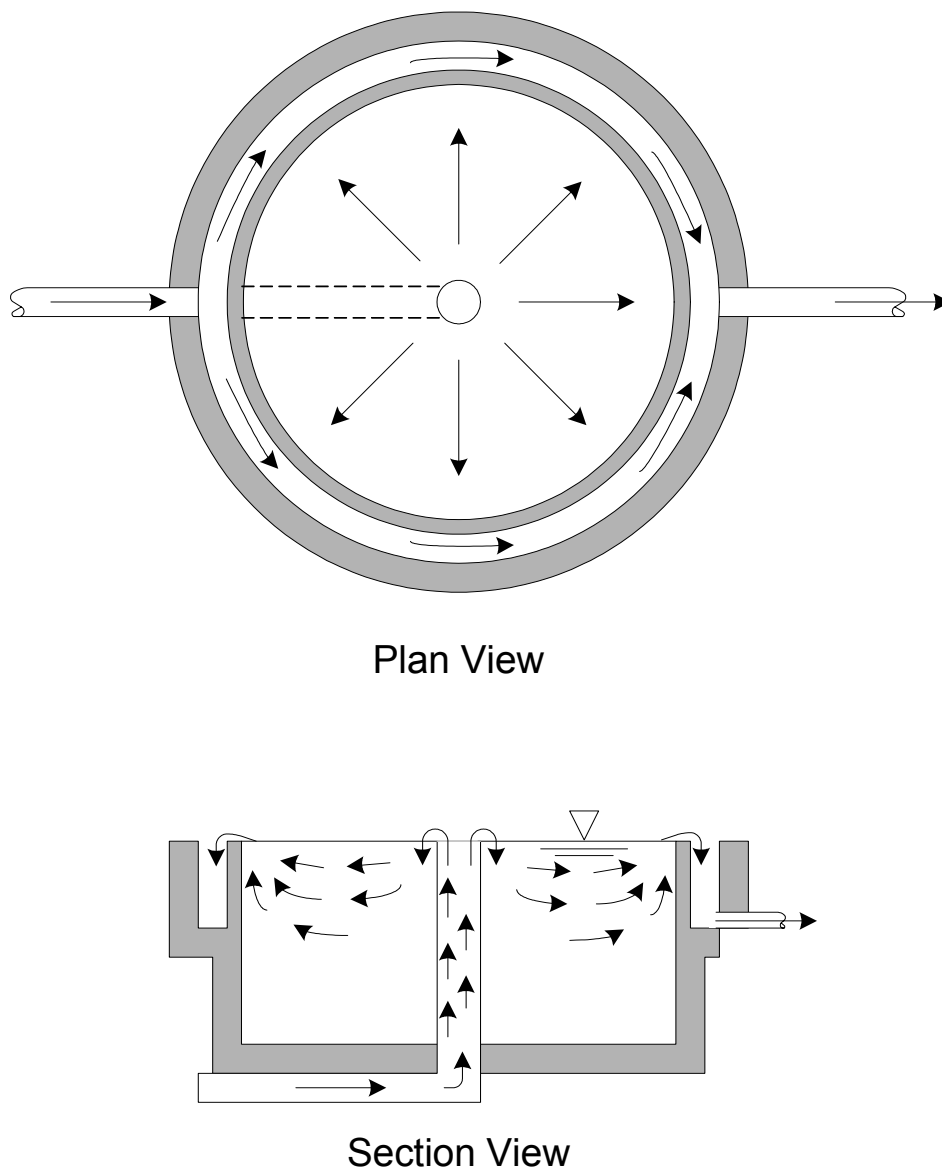**Figure G-4. Poor Baffling Conditions- Circular Contact Basin**
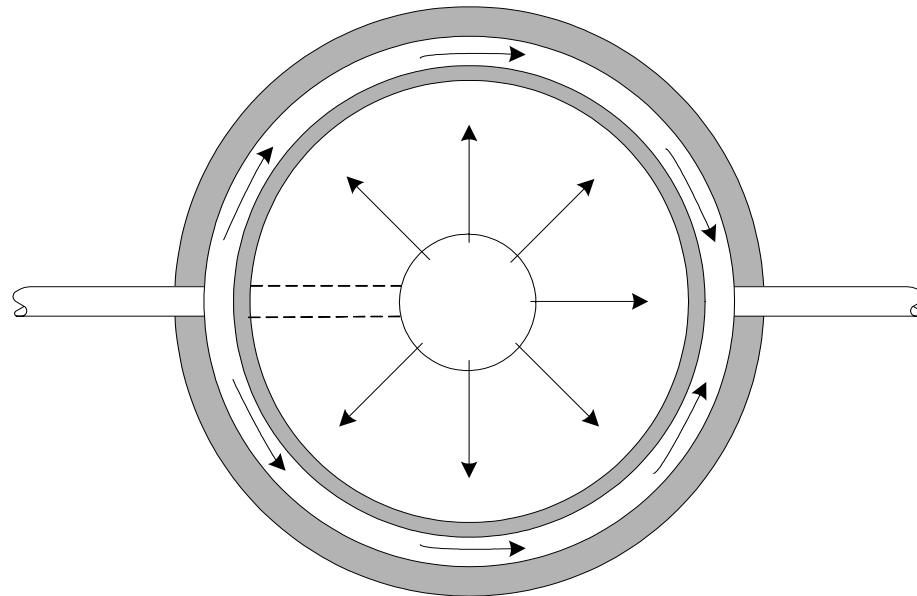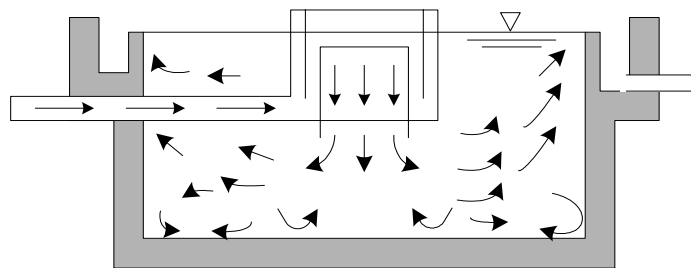

Plan View

Section View

Figure G-5. Average Baffling Conditions- Circular Contact Basin

Plan View

Section View

Superior baffling conditions are attained in the basin configuration shown on Figure G-6 through the addition of a perforated inlet baffle and submerged orifice outlet ports. As indicated by the flow pattern, more of the basin's volume is utilized due to uniform flow distribution created by the perforated baffle. Short circuiting is also minimized because only a small portion of flow passes directly through the perforated baffle wall from the inlet to the outlet ports.
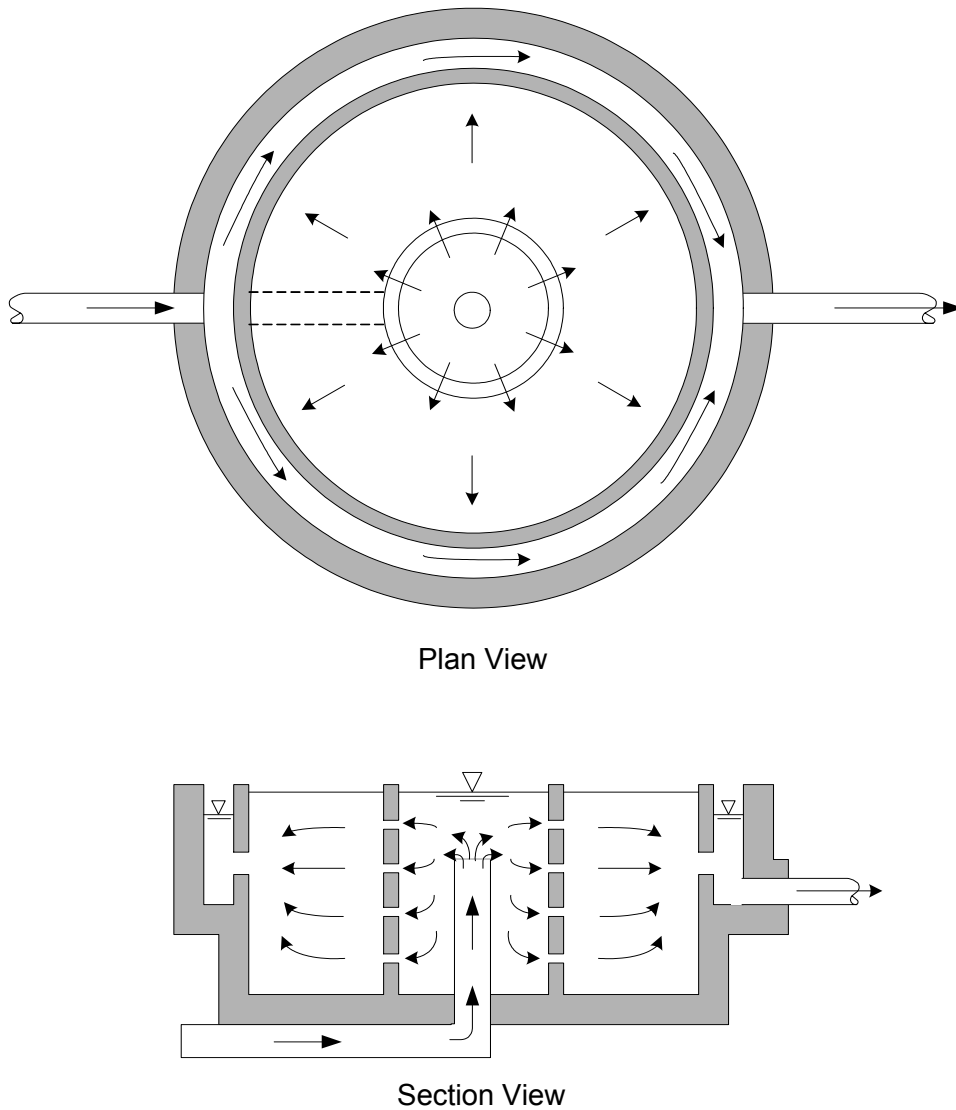
Figure G-6. Superior Baffling Conditions- Circular Contact Basin

Plan View

Section View

G.5 ADDITIONAL CONSIDERATIONS

Flocculation basins and ozone contactors represent water treatment processes with slightly different characteristics from those presented in Figures G-1 through G-6 because of the additional effects of mechanical agitation and mixing from ozone addition, respectively. Studies by Hudson (1975) indicated that a single-compartment flocculator had a T_{10}/T value less than 0.3, corresponding to a dead space zone of about 20 percent and a very high mixed flow zone of greater than 90 percent. In this study, two four-compartment flocculators, one with and the other without mechanical agitation, exhibited T_{10}/T values in the range of 0.5 to 0.7. This observation indicates that not only will compartmentation result in higher T_{10}/T values through better flow distribution, but also that the effects of agitation intensity on T_{10}/T are reduced where sufficient baffling exists. Therefore, regardless of the extent of agitation, baffled flocculation basins with two or more compartments should be considered to possess average baffling conditions ($T_{10}/T = 0.5$), whereas unbaffled, single-compartment flocculation basins are characteristic of poor baffling conditions ($T_{10}/T = 0.3$).

Similarly, multiple stage ozone contactors are baffled contact basins which show characteristics of average baffling conditions. Single stage ozone contactors should be considered as being poorly baffled. However, circular turbine ozone contactors may exhibit flow distribution characteristics that approach those of completely mixed basins, with a T_{10}/T of 0.1, as a result of the intense mixing.

In many cases, settling basins are integrated with flocculators. Data from Hudson (1975) indicates that poor baffling conditions at the flocculator/settling basin interface can result in backmixing from the settling basin to the flocculator. Therefore, settling basins that have integrated flocculators without effective inlet baffling should be considered as poorly baffled, with a T_{10}/T of 0.3, regardless of the outlet conditions, unless intra-basin baffling is employed to redistribute flow. If intra-basin and outlet baffling is utilized, then the baffling conditions should be considered average with a T_{10}/T of 0.5.

Filters are special treatment units because their design and function is dependent on flow distribution that is completely uniform. Except for a small portion of flow that short circuits the filter media by channeling along the walls of the filter, filter media baffling provides a high percentage of flow uniformity and can be considered superior baffling conditions for the purpose of determining T_{10}. As such, the T value can be obtained by subtracting the volume of the filter media, support gravel, and underdrains from the total volume and calculating the TDT by dividing this volume by the flow through the filter (Check with the State on what volume may be allowed in a filter). The TDT may then be multiplied by a factor of 0.7, corresponding to superior baffling conditions, to determine the T_{10} value.

G.6 CONCLUSIONS

The recommended T_{10}/T values and examples are presented as a guideline for use by the State in determining T_{10}. Conditions that are combinations or variations of the above examples may exist and warrant the use of intermediate T_{10}/T values such as 0.4 or 0.6. As

more data on tracer studies become available, specifically correlations between other physical characteristics of basins and the flow distribution efficiency parameters, further refinements to the T_{10}/T fractions and definitions of baffling conditions may be appropriate.

G.7 REFERENCES

EPA. 1991. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources.* Washington, D.C.

Hudson, H.E., Jr. 1975. Residence Times in Pretreatment. Journal AWWA, 67(1): 45-52.

Marske, D.M. and J.D. Boyle. 1973. Chlorine Contact Chamber Design – A Field Evaluation. Water and Sewage Works, January, pp. 70-77.

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Appendix H
Conservative Estimate and Interpolation Examples

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In some instances, the collected data for the disinfection profile will not coincide exactly with the values in the CT tables. The following examples present two methods on how to obtain $CT_{99.9}$ values. Systems should check with the State if these methods are acceptable for obtaining $CT_{99.9}$.

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Example H-1: Conservative Estimate Example for Obtaining CT$_{99.9}$
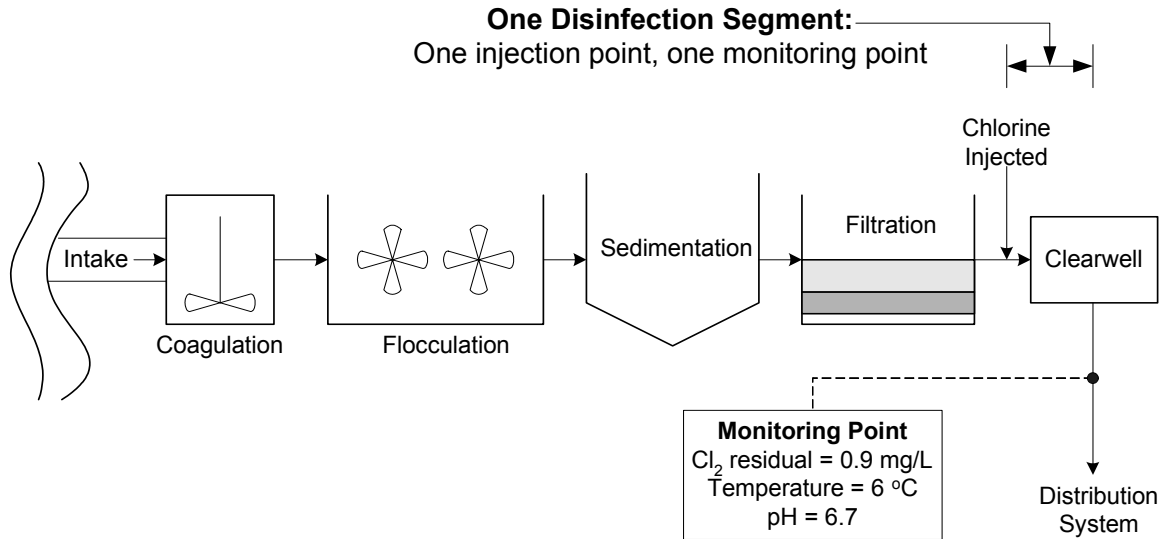
This example will demonstrate one method, Conservative Estimate, for obtaining CT$_{99.9}$ when collected data values are between values on the CT table. In this example a conventional filtration treatment system added chlorine prior to the clearwell and it was required to create a profile. The system must determine the *Giardia* log inactivation achieved through disinfection.

A. Determine the required CT$_{99.9}$ necessary to obtain 3-log *Giardia* inactivation.

The required CT value for 3-log *Giardia* inactivation (CT$_{99.9}$) may be obtained using CT Table B-1 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine.

Step 1. Round the temperature value.

Since the temperature of 6 $^{\circ}$C is not shown in the table, the next lowest temperature on the table, 5 $^{\circ}$C, is used to obtain a conservative estimate of CT$_{99.9}$. The lower temperature value was chosen since chlorine is less effective at lower temperatures.

Step 2. Round the pH value.

Since the pH of 6.7 is not shown in the table, the next highest pH, 7.0, is used to obtain a conservative estimate of CT$_{99.9}$. The higher pH value was chosen since chlorine is less effective at a higher pH.

Example H-1 continued

Step 3. Round the residual chlorine concentration value.

Since the residual chlorine concentration of 0.9 mg/L is not shown on the table, the next highest residual chlorine concentration, 1.0 mg/L, is used to obtain a conservative estimate of $CT_{99.9}$. A higher residual chlorine concentration is used to obtain a higher required $CT_{99.9}$ value, which will result in a lower calculated log inactivation ratio value.

Step 4. Determine $CT_{99.9}$.

In this example the $CT_{99.9}$ is 149 min-mg/L for a pH of 7.0, temperature of 5 ^{o}C, and $C_{chlorine}$ of 1.0 mg/L. The relevant section of Table B-1 is reprinted below and the pertinent section of the table is highlighted.

Excerpt from Table B-1:

CT values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine (5°C portion of table for 0.4 to 1.2 mg/L)

Chlorine Concentration (mg/L)	Temperature 5 ^{o}C						
			pH				
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	97	117	139	166	198	236	279
0.6	100	120	143	171	204	244	291
0.8	103	122	146	175	210	252	301
1.0	105	125	149	179	216	260	312
1.2	107	127	152	183	221	267	320

Example H-2: Interpolation Example for Obtaining CT$_{99.9}$

One Disinfection Segment:
One injection point, one monitoring point

Monitoring Point
Cl$_2$ residual = 0.9 mg/L
Temperature = 6 °C
pH = 6.7
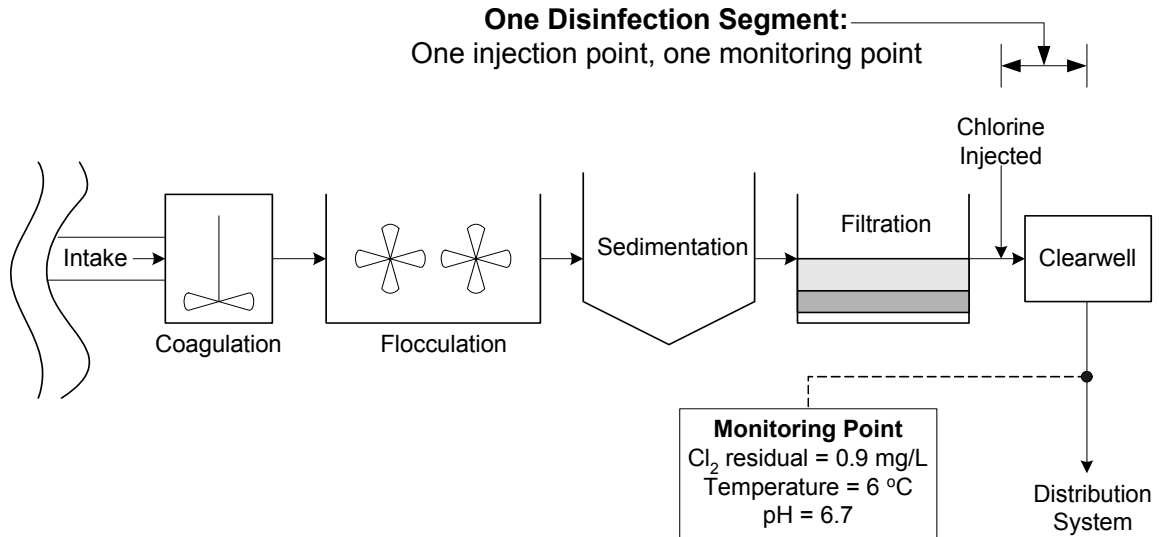
This example will demonstrate another method, interpolation, for obtaining CT$_{99.9}$ when collected data values are between values on the CT table. In this example a conventional filtration treatment system added chlorine prior to the clearwell and it was required to create a profile. The system must determine the *Giardia* log inactivation achieved through disinfection.

A. Determine the required CT$_{99.9}$ necessary to obtain 3-log *Giardia* inactivation.

The required CT value for 3-log *Giardia* inactivation (CT$_{99.9}$) may be obtained using CT Table B-1 in Appendix B, CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine. Since the temperature of 6 °C, the pH of 6.7, and the residual chlorine concentration of 0.9 mg/L are not shown on the table, interpolation is used to determine the CT$_{99.9}$ value.

Example H-2 continued

Step 1. Interpolate for CT_{99.9} at pH of 6.7 at the next lowest temperature of 5 °C and the next lowest residual chlorine concentration of 0.8 mg/L.

Excerpt from Table B-1:

CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine (5°C portion of table for 0.4 to 1.2 mg/L)

Chlorine Concentration (mg/L)	Temperature 5 °C						
	pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	97	117	139	166	198	236	279
0.6	100	120	143	171	204	244	291
0.8	103	122	146	175	210	252	301
1.0	105	125	149	179	216	260	312
1.2	107	127	152	183	221	267	320

$$\frac{(CT_{99.9} \text{ at pH } 7.0) - (CT_{99.9} \text{ at pH } 6.5)}{\text{pH } 7.0 - \text{pH } 6.5} = \frac{(CT_{99.9} \text{ at pH } 6.7) - (CT_{99.9} \text{ at pH } 6.5)}{\text{pH } 6.7 - \text{pH } 6.5}$$

$$\frac{146 \text{ min-mg/L} - 122 \text{ min-mg/L}}{7.0 - 6.5} = \frac{(CT_{99.9} \text{ at pH } 6.7) - 122 \text{ min-mg/L}}{6.7 - 6.5}$$

$$\frac{24 \text{ min-mg/L}}{0.5} = \frac{(CT_{99.9} \text{ at pH } 6.7) - 122 \text{ min-mg/L}}{0.2}$$

$$\frac{24 \text{ min-mg/L} \times 0.2}{0.5} = (CT_{99.9} \text{ at pH } 6.7) - 122 \text{ min-mg/L}$$

$$9.6 \text{ min-mg/L} = (CT_{99.9} \text{ at pH } 6.7) - 122 \text{ min-mg/L}$$

$$CT_{99.9} \text{ at pH } 6.7 = 9.6 \text{ min-mg/L} + 122 \text{ min-mg/L}$$

$$CT_{99.9} \text{ at pH } 6.7 = 131.6 \text{ min-mg/L}$$

Example H-2 continued

Step 2. Interpolate for CT$_{99.9}$ at pH of 6.7 at the next highest temperature of 10 ^{o}C and the next lowest residual chlorine concentration of 0.8 mg/L.

Excerpt from Table B-1:

CT Values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine (10°C portion of table for 0.4 to 1.2 mg/L)

Chlorine Concentration (mg/L)	Temperature 10 °C						
	pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	73	88	104	125	149	177	209
0.6	75	90	107	128	153	183	218
0.8	78	92	110	131	158	189	226
1.0	79	94	112	134	162	195	234
1.2	80	95	114	137	166	200	240

$$\frac{(CT_{99.9} \text{ at pH } 7.0) - (CT_{99.9} \text{ at pH } 6.5)}{\text{pH } 7.0 - \text{pH } 6.5} = \frac{(CT_{99.9} \text{ at pH } 6.7) - (CT_{99.9} \text{ at pH } 6.5)}{\text{pH } 6.7 - \text{pH } 6.5}$$

$$\frac{110 \text{ min-mg/L} - 92 \text{ min-mg/L}}{7.0 - 6.5} = \frac{(CT_{99.9} \text{ at pH } 6.7) - 92 \text{ min-mg/L}}{6.7 - 6.5}$$

$$\frac{18 \text{ min-mg/L}}{0.5} = \frac{(CT_{99.9} \text{ at pH } 6.7) - 92 \text{ min-mg/L}}{0.2}$$

$$\frac{18 \text{ min-mg/L x } 0.2}{0.5} = (CT_{99.9} \text{ at pH } 6.7) - 92 \text{ min-mg/L}$$

$$7.2 \text{ min-mg/L} = (CT_{99.9} \text{ at pH } 6.7) - 92 \text{ min-mg/L}$$

$$CT_{99.9} \text{ at pH } 6.7 = 7.2 \text{ min-mg/L} + 92 \text{ min-mg/L}$$

$$CT_{99.9} \text{ at pH } 6.7 = 99.2 \text{ min-mg/L}$$

Example H-2 continued

Step 3. Interpolate for CT$_{99.9}$ at pH of 6.7, temperature of 6°C, and the next lowest residual chlorine concentration of 0.8 mg/L.

The table below summarizes the CT$_{99.9}$ values determined at a pH of 6.7, residual chlorine concentration of 0.8 mg/L, and temperatures of 5 ^{o}C and 10 ^{o}C.

pH = 6.7		
Chlorine Concentration	**Temperature**	
	5 ^{o}C	**10 ^{o}C**
0.8 mg/L	131.6 min-mg/L	99.2 min-mg/L

$$\frac{(CT_{99.9} \text{ at } 10 \,^o\text{C}) - (CT_{99.9} \text{ at } 5 \,^o\text{C})}{10 \,^o\text{C} - 5 \,^o\text{C}} = \frac{(CT_{99.9} \text{ at } 6 \,^o\text{C}) - (CT_{99.9} \text{ at } 5 \,^o\text{C})}{6 \,^o\text{C} - 5 \,^o\text{C}}$$

$$\frac{99.2 \text{ min-mg/L} - 131.6 \text{ min-mg/L}}{10 \,^o\text{C} - 5 \,^o\text{C}} = \frac{(CT_{99.9} \text{ at } 6 \,^o\text{C}) - 131.6 \text{ min-mg/L}}{6 \,^o\text{C} - 5 \,^o\text{C}}$$

$$\frac{-32.4 \text{ min-mg/L}}{5 \,^o\text{C}} = \frac{(CT_{99.9} \text{ at } 6 \,^o\text{C}) - 131.6 \text{ min-mg/L}}{1 \,^o\text{C}}$$

$$\frac{-32.4 \text{ min-mg/L x } 1 \,^o\text{C}}{5 \,^o\text{C}} = (CT_{99.9} \text{ at } 6 \,^o\text{C}) - 131.6 \text{ min-mg/L}$$

$-6.48 \text{ min-mg/L} = (CT_{99.9} \text{ at } 6 \,^o\text{C}) - 131.6 \text{ min-mg/L}$

$CT_{99.9} \text{ at } 6 \,^o\text{C} = -6.48 \text{ min-mg/L} + 131.6 \text{ min-mg/L}$

CT$_{99.9}$ at 6 ^{o}C = 125.1 min-mg/L

CT$_{99.9}$ at a pH of 6.7, temperature of 6°C, and residual chlorine concentration of 0.8 mg/L is 125.1 min-mg/L.

Example H-2 continued

Step 4. Repeat steps 1 through 3 at the same pH and temperatures, but with a residual chlorine concentration of 1.0 mg/L.

The results are summarized in the table, below.

pH	Temperature (^{o}C)	Residual Chlorine Conc. (mg/L)	$CT_{99.9}$ (min-mg/L)
6.7	5	1.0	134.6
6.7	10	1.0	101.2
6.7	6	1.0	127.9

$CT_{99.9}$ at a pH of 6.7, temperature of 6°C, and residual chlorine concentration of 1.0 mg/L is 127.9 min-mg/L.

Step 5. Interpolate for $CT_{99.9}$ at pH of 6.7, temperature of 6°C, and residual chlorine concentration of 0.9 mg/L.

The table below summarizes the $CT_{99.9}$ values determined at a pH of 6.7, temperature of 6°C, and residual chlorine concentrations of 0.8 mg/L and 1.0 mg/L.

pH = 6.7		
	Chlorine Residual Conc.	
Temperature	**0.8 mg/L**	**1.0 mg/L**
6°C	125.1 min-mg/L	127.9 min-mg/L

$$\frac{(CT_{99.9} \text{ at } 1.0 \text{ mg/L}) - (CT_{99.9} \text{ at } 0.8 \text{ mg/L})}{1.0 \text{ mg/L} - 0.8 \text{ mg/L}} = \frac{(CT_{99.9} \text{ at } 0.9 \text{ mg/L}) - (CT_{99.9} \text{ at } 0.8 \text{ mg/L})}{0.9 \text{ mg/L} - 0.8 \text{ mg/L}}$$

$$\frac{127.9 \text{ min-mg/L} - 125.1 \text{ min-mg/L}}{1.0 \text{ mg/L} - 0.8 \text{ mg/L}} = \frac{(CT_{99.9} \text{ at } 0.9 \text{ mg/L}) - 125.1 \text{ min-mg/L}}{0.9 \text{ mg/L} - 0.8 \text{ mg/L}}$$

$$\frac{2.8 \text{ min-mg/L}}{0.2 \text{ mg/L}} = \frac{(CT_{99.9} \text{ at } 0.9 \text{ mg/L}) - 125.1 \text{ min-mg/L}}{0.1 \text{ mg/L}}$$

$$\frac{2.8 \text{ min-mg/L x } 0.1 \text{ mg/L}}{0.2 \text{ mg/L}} = (CT_{99.9} \text{ at } 0.9 \text{ mg/L}) - 125.1 \text{ min-mg/L}$$

$$1.4 \text{ min-mg/L} = (CT_{99.9} \text{ at } 0.9 \text{ mg/L}) - 125.1 \text{ min-mg/L}$$

$$CT_{99.9} \text{ at } 0.9 \text{ mg/L} = 1.4 \text{ min-mg/L} + 125.1 \text{ min-mg/L}$$

Example H-2 continued

$CT_{99.9}$ **at 0.9 mg/L = 126.5 min-mg/L**

$CT_{99.9}$ **at a temperature of $6^{o}C$, pH of 6.7, and residual chlorine concentration of 0.9 mg/L is 126.5 min-mg/L.**